A MANUAL

OF

FOREST ENGINEERING FOR INDIA.

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A MANUAL

OF

FOREST ENGINEERING FOR INDIA

BY

CHARLES GILBERT ROGERS,

FELLOW OF COOPER'S HILL, DEPUTY CONSERVATOR OF FORESTS, IMPERIAL FOREST SERVICE OF INDIA.

VOLUME I.

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PREFACE.

THIS Manual has been written by order of the Government of India for the use of Forest Officers in India in the first instance, but will, it is hoped, prove of some practical value to the general public, and especially to that section of the community who are engaged directly in the management of tea and coffee gardens, indigo concerns, and in agricultural pursuits generally.

The scope of the work is laid down in the Resolution passed by the Board of Control of the Imperial Forest School, Dehra Dûn, which assembled at Dehra in March, 1893, under the presidentship of Mr. B. Ribbentrop, C.I.E., Inspector-General of Forests to the Government of India. The Board placed on record their opinion that a Manual of Forest Engineering should be prepared, that the course of Engineering at present taught at the School meets all requirements, and that the general arrangement of the Manual should be based upon the School Syllabus of the course of Forest Engineering. While recognizing the value of the notes of lectures delivered at the Forest School by Lieutenant-Colonel Bailey, R.E., formerly Director of that Institution, and Mr. A. G. Hobart-Hampden, and edited by the latter officer, the Board considered that those notes would require considerable addition and re-arrangement in order to render them complete and in conformity with the School Syllabus. They further resolved that the Manual should be elaborated beyond the requirements of the school curriculum, so as to be useful for reference to the officers of the Department and to the public generally.

In order to carry this proposal into practical effect, and in order to utilize local experience and collect examples and illustrations of local works or practice, they considered that the preparation of the Manual should be entrusted to an editor who should have authority to correspond with Conservators of Forests throughout India.

The preparation of the Manual was entrusted to me, and proofs of the different parts of the work have been sent gradually, as they became ready, to the Inspector-General of Forests to the Government of India, and all Conservators of Forests, for circulation among such Forest Officers as they might select, for the purpose of recording any suggestions which they had to make.

In the preparation of the draft of the different parts of the Manual it has been my endeavour to bring together all the information that was available on the subjects treated of, so as to indicate what was known and what was not known; and thus to induce Forest Officers and others to whom the draft was sent to criticize the information collected, to indicate whether it was in accord with their practical experience or not; to add to the information where necessary, and to state what parts of the information collected was, in their opinion, useless to Forest Officers, or at variance with local practice.

This course of action has necessarily delayed the publication of the Manual.

The value of the Manual as a book of reference has been greatly increased by the circulation of the draft among Indian Forest Officers and others who have been kind enough to give me the benefit of their experience;

and the Manual may, I think, be taken to represent the experience of the Department as a whole, instead of that of one individual. It is a great pleasure to me to place on record my indebtedness to those Forest Officers and others who have so kindly favoured me with criticisms and suggestions—the result of their practical experience in many parts of the Indian Empire—and who have furnished me with much valuable information concerning local works and practices of which I had no personal knowledge.

The Manual has been divided into the following parts :

Part I.—Building Materials.
Part II.—Building Construction.
Part III.—Road Making.
Part IV.—Bridges.
Part V.—Transport of Timber.
Part VI.—Wells.
Part VII.—Construction of Embankments and Water Channels. River Training Works.
Part VIII.—Demarcation of Forests.

Parts I and II will form the first, Parts III and IV the second, and Parts V to VIII the third and last volume.

The first two volumes contain information which will be useful to anyone who is interested in simple engineering problems, while the third volume contains those parts of the subject which are of more special interest to a Forest Officer.

This Manual is not intended to take the place of the many excellent works on civil engineering which already exist; but will, it is hoped, supplement these, and fill a gap which has long been felt by those who have received

no special training in engineering, and who find themselves called upon to carry out simple engineering works which do not require a high and special course of training—situated as they often are in places where it is impossible to obtain the advice or services of a specially trained engineer, and where they have to depend entirely upon their own resources and initiative.

The Manual is intended as a book of reference for practical men as well as a text book for the use of students. Consequently, it has been my endeavour to make the information recorded on each and every subject treated of complete in itself, thus obviating, as far as practicable, the necessity of referring to other parts of the book for additional information bearing on the subject; as a person engaged on practical work has not time to read straight through any book, and naturally would expect to find all the information that he would require on any given subject as far as possible in one and the same place.

This procedure has necessarily involved a certain amount of repetition, which is unavoidable if the object stated above is to be attained.

The Index has been compiled with great care, and has been made as full as possible, with a view to rendering the information recorded easily accessible to all, and allowing of ready reference to the different places in which information has been recorded on one and the same subject.

The engineering works which a Forest Officer, or landed proprietor, in an out-of-the-way part of the world is called upon to execute have generally to be carried out with crude appliances in an economical manner;

and in the great majority of cases only materials which are obtained locally can be used, owing to the great cost of transport of manufactured material from the nearest market where it can be purchased to the site of the work. This condition in many instances practically precludes the use of iron beams and castings, etc., which otherwise it would be very desirable to use, and these have to be replaced by such timber as can be obtained locally.

The choice of materials is thus dependent upon local circumstances, and differs considerably from place to place; and structures involving the use of iron and steel have consequently only been occasionally referred to.

The use of technical terms has been avoided as far as possible, and an attempt has been made to render the Manual intelligible to those who have had no special training in engineering. It has been my aim to place before my readers all the information (within the scope of the work) that they are likely to require, and thus to avoid the necessity of reference to other works on civil engineering. How far I have succeeded I must leave it to my readers to judge.

Exception may be taken to the inclusion of carpentry and joinery in *Part I.—Building Materials.* My reason for placing the detailed consideration of the construction of joints in timber in Part I. is simply one of convenience for reference. The joints considered may be required in the construction of floors and roofs (*Part II*) or in the construction of bridges (*Part IV*). Consequently I have considered it advisable not to go into the question of their proper formation in either of these parts, but to place the subject in a part which precedes,

both of them, and to which reference can be made as required.

The illustrations have been drawn, as far as practicable, to scale; and have been, in the majority of cases, dimensioned as well; and will, it is hoped, prove of considerable practical use. Much valuable information, which has not been repeated in the text, will be found in the description of the several figures. It has been considered advisable to add detailed descriptions of the majority of the illustrations in order to render them perfectly intelligible without reference to the text.

By far the majority of the illustrations are original, and have, whenever practicable, been taken from actual constructions, a fact which will add much to their intrinsic value.

Those illustrations which have been supplied by Forest Officers and other helpers have been duly acknowledged, with the exception of a few which have been taken from Mr. A. G. Hobart-Hampden's Notes on Forest Engineering, the original source of which is not accurately known. I am indebted to Messrs. John Fowler & Co., Limited, Leeds, for the wood-blocks of Figures 43, 44, 45, 46, 47, 48, 49, and 50, Volume III.; to the President of the Administrative Council of the "Société nouvelle des établissements Décauville ainé" of Petit Bourg, Seine et Oise, France, for the electrotypes of Figures 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, and 61 of the same volume; and to Messrs. T. W. Palmer & Co., 5, Victoria Street, London, S.W., for the electrotype of figure 80, Volume II. Figure 86 of the same volume appeared first in *Indian Engineering*, edited by Pat.

Doyle, Esq., C.E., who kindly gave me permission to reduce that drawing for the illustration of this work.

In the preparation of the Manual many of the standard works on Civil Engineering have been consulted, and among these the following should be specially mentioned. References have been made in footnotes to the authorities who have been principally consulted :—

Notes on Building Construction arranged to meet the requirements of the Syllabus of the Science and Art Department of the Committee of Council on Education, South Kensington. (London: Longmans, Green & Co.)

The Roorkee Treatise on Civil Engineering in India, 3rd Edition, edited by Major A. M. Lang, R.E. (Roorkee: Thomason College Press.)

A Manual of Civil Engineering, by J. M. Rankine, C.E., 16th Edition, thoroughly revised by W. J. Millar, C.E. (London: Charles Griffin & Co., Exeter Street, Strand.)

Elementary Principles of Carpentry, by Thomas Tredgold, revised and partially rewritten by J. T. Hurst, C.E., 4th Edition. (London: E. and F. N. Spon, 16, Charing Cross.)

A Treatise on Mountain Roads, by Lieutenant-General H. St. Clair Wilkins, R.E. (London : E. and F. N. Spon, 16, Charing Cross.)

An Elementary Course of Civil Engineering for the use of the students of the Upper Subordinate class *of the Civil Engineering College of Madras.* (Lawrence Asylum Press, Mount Road, Madras.)

Lime and Cement, by A. H. Heath. (London: E. and F. N. Spon, 16, Charing Cross.)

A Rudimentary Treatise on the Blasting and

Quarrying of Stone, by General Sir J. F. Burgoyne. (London: J. Weale and Son.)

The Manual has been written under the general editorship of Mr. J. S. Gamble, Director of the Imperial Forest School, Dehra Dûn, to whom my acknowledgments are due for general advice and for notes which formed the basis of the draft of *Part VIII.—The Demarcation of Forests.*

My thanks are due to those Indian Forest Officers who have been good enough to criticize the draft of the Manual circulated among them, to make suggestions and to add much useful information with regard to local works and practices—the result of their personal experience.

I have endeavoured to acknowledge the information received from them as far as practicable in the text. My thanks are specially due to the following Indian Forest Officers:—Mr. A. G. Hobart-Hampden, North-Western Provinces and Oudh; Messrs. F. A. Lodge, A. W. Lushington, and H. J. Porter, Madras Presidency; Mr. D. P. Copeland, Assam; Mr. F. Gleadow, Bombay Presidency, Deputy Director, Imperial Forest School, Dehra Dûn; Messrs. J. W. Oliver, E. A. O'Bryen, and C. Q. Corbett, Burma.

The Manager of the Bombay-Burma Trading Company has given me much valuable information with regard to the construction and use of the timber carts employed in the extraction of teak logs in Upper Burma.

Mr. A. H. Heath, A.M.I.C.E., Assistant Professor of Engineering, Royal Indian Engineering College, Cooper's Hill, England, has given me material help in the revision of the whole work, and has rewritten the

articles on piles and pile driving, and on masonry bridges in Volume II, Part IV, and has furnished me with the sketches from which the illustrations of those articles have been made.

Professor T. A. Hearson, M.I.C.E., and Mr. R. Woods, F.C.H., both on the staff of the same College, have given me assistance and advice in the portions of the Manual relating to roofs and bridges.

Mr. C. E. Dupuis, F.C.H., Executive Engineer, Public Works Department, Irrigation Branch, has kindly revised the portions of the Manual which deal with the calculation of the dimensions of the different parts of a suspension bridge, and has furnished me with much practical information with regard to the construction of small irrigation channels and of spurs for the protection of river banks from erosion. He has also written Appendix I to Vol. I on Bull's Trench Kiln.

Mr. R. N. Hodges, Superintending Engineer (Public Works Department), has looked through the draft of the first two volumes, and has given me many practical hints which are of much value.

Finally, I wish to acknowledge the consistently kind help and advice given to me by Dr. William Schlich, Ph.D., C.I.E., during the preparation of this work.

C. GILBERT ROGERS.

SIMLA,
8th September, 1899.

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PART I.

A MANUAL OF FOREST ENGINEERING.

Part I.—BUILDING MATERIALS.

SECTION I.—STONE.

§ I. QUALITIES OF STONE.—The chief qualities of stone which it is necessary to consider, so far as its use in the construction of forest works is concerned, are—

(1) strength,
(2) durability,
(3) the facility with which it can be worked.

(1) *The strength of stone.*—By the strength of a stone is understood its power to resist the crushing force exerted on it by the weight which it has to support. In ordinary forest works, this force is not considerable, and it may be assumed that any stone which is sufficiently durable will be also sufficiently strong for the purpose for which it is required.

(2) *The durability of stone.*—By durability, as applied to stone, is understood its power to resist the decomposing action of the atmosphere and the other external influences to which it may be subjected. Durability is a very necessary quality in stone, and a deficiency in this respect may endanger the stability of the most carefully constructed building.

The durability of a stone depends upon—

(*a*) the action of the atmosphere,
(*b*) its chemical composition,
(*c*) its physical structure,
(*d*) its position in the building.

(*a*) *The influence of the atmosphere.*—The nature and extent of the atmospheric agencies which act upon a stone affect its durability very considerably. A stone is more durable in a dry atmosphere than in a moist one. Acid fumes, either in the air, or dissolved in rain, have a harmful influence upon stone. The number of rainy days and the total annual rainfall are of importance in determining the durability of stone. The decomposing effect of the atmosphere upon a stone is spoken of as *weathering*; a stone which is but little affected by the atmosphere is said to weather well, while one which is rapidly decomposed on exposure to the air is said to weather badly.

Some stones, however, harden on exposure to air, *e.g.*, laterite, the limestone of Kullada hill in Ganjam and the gneiss of Kondavid hill in the Kistna district. (*A. W. Lushington.*)

(*b*) *Its chemical composition.*—As far as durability is concerned, the chemical composition of a stone should be such as to enable it to resist the action of the air and of the harmful compounds which the air contains. The atmosphere always contains some carbon dioxide, and, near manufacturing cities, acid fumes as well. These substances are dissolved in rain or combine with the moisture of the air and are thus carried into the pores of the stone. Carbon dioxide will ultimately seriously injure any stone which has a considerable quantity of magnesium or calcium carbonate in its composition. Oxygen acts deleteriously on stones containing much iron. Lichens sometimes hasten decay in stones.

(*c*) *Physical structure.*—The physical structure of a stone is of great importance in determining its relative durability. It depends very much on the origin of the stone. Take for example marble and chalk: their chemical composition is the same, but the former is a hard, strong, highly indurated, crystal-

line and durable rock; while the latter is a soft powdery material without either strength or cohesion. Compare again the respective durabilities of a hard stratified slate, a soft fissile shale, and a simple sedimentary deposit of mud; all these three bodies may have the same chemical composition, and their different durabilities depend entirely upon their different ages. Quartzite and a soft sandstone may have the same chemical composition; the former is one of the most durable of stones, the latter one of the least durable. Quartzite is a metamorphic rock, sandstone a sedimentary one.

A rock with a crystalline structure is, as a rule, more durable than one which is not crystalline. A stone with a porous structure is generally less durable than one which has a dense homogeneous structure. Stones with a close grain are more durable than those which have an open grain, provided in each case that their chemical composition is identical. A stone which is homogeneous in structure is generally durable.

If a stone consists of grains held together by a cementing material, the durability of the stone will depend upon that of its component parts; if both are lasting, the stone will be durable; if the cementing material is easily destroyed, the stone will crumble, and if the grains are not durable it will become porous. No stone which has begun to *weather* (see page 2) should be used in the construction of a building.

(*d*) *The position of the stone in the building.*—Stones placed in a part of a building exposed to rain are, as a rule, more liable to be decomposed or disintegrated than when placed so as to be sheltered from the rain. In damp climates, stones protected from wind and sun are more liable to decay than those exposed to those influences, because rain falling on them, containing as it often does, acids in solution, will dry out very slowly.

The outer surfaces of stones subjected to the action of frost, or to alternations of intense heat and cold, are liable to crack or flake off.

All stones, especially those which are distinctly stratified, should be placed in walls, in the position in which they were *originally* deposited or in this position inverted. If the planes of stratification are placed parallel to the surface of the wall, the surface of the stone is liable to peel off in flakes.

FIG. 1.

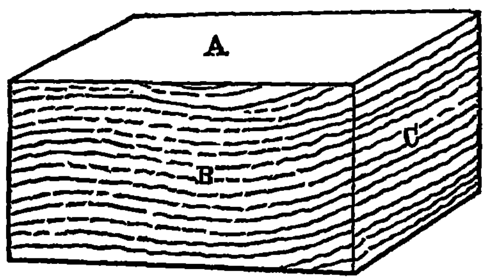


Figure 1 represents a block of stratified stone, the broken lines show the lines of stratification. In placing such a stone in a vertical wall it should be laid with the face A horizontal. If such a stone were laid with either of the faces B or C horizontal, the laminæ would split off in flakes during the process of weathering.

In arches, the natural bed of the stones should be placed perpendicularly to the *thrust* on the stone (*i.e.*, to the resultant of the forces acting on it); the beds of stratification should be parallel to the centre line of the arch and perpendicular to its face.

(3) *Facility of working.*—This is of importance from an economic point of view. The ease with which a stone can be shaped depends upon its hardness, structural soundness, freedom from flaws, faults, or lamination, and the presence or absence of natural fractures and cleavages.

§ 2. Besides the qualities of stone which have just been considered, there are two other less important ones which should be mentioned. These are *hardness* and *weight.*

The *hardness* of a stone is of importance when we wish to preserve sharp angles, or in cases where the stone is exposed

to the destructive action of water. It does not necessarily follow that because a stone is hard it will be durable, but the harder a stone is the more expensive will it be to fashion it.

The *weight* of a stone is occasionally of importance, where there is a choice of stones. In such cases, the heavier stones should be placed in the foundations and the lighter ones in the superstructure.

In the construction of embankments or dams to form tanks, retaining walls and protective works generally, the size and weight of the stones used is of great importance. A dam constructed of very large heavy stones will resist the action of a stream in flood very much more effectively than a considerably more massive one built of small stones.

§ 3. TESTS FOR THE DURABILITY OF STONE.—In comparing the durability of stones of the same class, the least porous and the heaviest (and consequently strongest) will be the most durable in an atmosphere which has no special tendency to attack the individual constituents of the stone itself.

The examination of the freshly broken surface of a stone will often yield a considerable amount of information as to its durability. If the surface is bright, clean, and sharp, and if the grains are well cemented together, the stone will, as a rule, be durable; if, however, the surface is dull and earthy and the cementing material weak, the stone will be liable to decay.

Absorption of water.—Another good guide to the relative durability of different stones lies in their power of absorbing water. The stones to be examined should be weighed when dry, and then immersed in water for 24 hours, and the stone which absorbs the smallest percentage of its weight of water will be the most durable.

The presence of earthy or mineral matter, easily soluble in water, may be detected by placing moistened fragments of the stone in a glass of clean water and leaving it undisturbed for half an hour; the water should then be stirred vigorously, and if there is much earthy or easily soluble matter present, the water will become discoloured.

Effect of acid.—If we wish to ascertain if a certain stone is likely to resist the acid fumes of town air we should place the stone to be tested for some days in a solution of dilute hydrochloric or sulphuric acid. The effect of the dilute acid on the stone will serve as a guide as to the probable effect of town air on it.

§ 4. PREPARATION OF BUILDING STONE.—Stone for building purposes in India may be obtained from quarries or collected from river beds (boulders). If boulders are used, their surfaces *must* be roughened by knocking off portions of their water-worn faces before they are placed in the wall. Boulders should only be used when no other kind of stone is available locally. The process of obtaining stone from the place where it is found naturally in the ground is called *quarrying.*

Stone situated near the surface of the soil, and which has consequently been subjected to weathering influences, is not so durable as that which is found lower down. No stone which has been perceptibly weathered should be taken from a quarry. Before opening a quarry we must consider how the stone may be extracted in the most economical manner. A quarry should be opened at the side, not at the top, of a hill, and the road leading to it should have as easy a gradient as possible.

In quarries, stone found in large masses is usually subdivided into smaller pieces by natural joints, which are either due to stratification, faults or cleavage. The stone can be separated along these lines more easily than in any other direction; where these joints are well defined, blocks of stone of suitable sizes can often be extracted by means of steel levers or picks. Where joints do not exist, or where smaller blocks are required, they may often be obtained by drilling a line of holes situated at short and regular intervals from each other in the required direction, and then placing a series of conical steel-pointed pins in these holes: the rock is split in the required direction, by striking the pins smartly and simultaneously with hammers. Where marked cleavage planes exist, pieces of stone can some-

times be split off by driving dry, hard, wooden pegs into the rock along the lines of the cleavage, the pegs may be moistened and so made to swell if the rock does not split easily.

In Southern India pieces of granite are removed from the massive deposits in which it occurs by *burning.* A fire is lit on the top of the stone and slowly moved along the line where it is required to split the rock. A crack follows the line of fire, and the blocks thus split off are removed by levers. Sometimes it is necessary to pour water on the heated rock in order to make it split, but this is not always the case. All the stones required for the Kistna Bridge were obtained in this way. (*A. W. Lushington.*)

The following description of the way in which the stone required for the Kistna Bridge was quarried is taken from "Indian Engineering" for August 25th, 1894:

Fires of brushwood were lighted near a likely looking edge, either natural or artificial, where there was a step of the desired thickness. The fires were then gradually moved back and back from the edge, the rate of progression being regulated by the solid or hollow note given out by a pebble held in the hand and beaten on the surface of the rock. When the crack was considered to have gone far enough, the flake was detached by frequent blows of a boulder flung down on it, or by means of a 14 lb. sledge hammer. The crack resulting from the fire was usually fairly parallel to the surface; perhaps in a stone 3 feet long the after end might be an inch thinner than the forward end. The vertical joints due to the hammer were usually very clean and rectangular. (*F. J. E. Spring.*)

When pieces of stone cannot be removed by any of the above mentioned methods, blasting must be resorted to. The process of blasting will be fully described in connection with road-making (see Vol. II, Part III, Road-making, section 3).

§ 5. Kinds of stone.—A few of the commoner kinds of stone which are used in building construction in India may be briefly referred to. They may be divided into the following large groups:—

(1) Siliceous, where silica is the principal constituent.
(2) Argillaceous, or clayey.
(3) Calcareous, where calcium carbonate predominates.

1. *Siliceous stones.*—These generally consist of hard and durable crystalline grains cemented together by some other material; and hence, if they decay, it is due to the destruction of the cementing matter or to water freezing in the pores of the stone.

The chief siliceous stones used in India are granite, gneiss, mica-schist, trap, basalt and sandstone:

(*a*) *Granite and Gneiss.*—Granite and granitoid gneiss are found very extensively in India. In Southern India, in Mysore, and the

districts of Ganjam, Kistna, Nellore and Chingleput; in the Bundelkand district of Central India; in the Garo and Khasia Hills in Assam; in Chota Nagpur and generally in the Himalaya. The composition and physical characters of gneiss vary very much indeed in different localities; in some parts of the Himalaya (Jaunsar) it is practically a hard quartzite, with very little or no felspar, and only mica in very small thin lamina; in other parts, at lower elevations, it is of the typical foliated nature. In many parts of India, gneiss resembles true granite, very much in composition and character.

Granite consists of quartz, mica and felspar in varying proportions, the size of the crystals of the different mineral constituents also varies very much. The best granite is that which contains the most silica and the least felspar and mica. Silica is almost indestructible, whilst felspar disintegrates and mica decomposes. The felspar crystals should be well defined but not too large. Being very hard, granite is difficult to work, but is extremely durable. It should be shaped and dressed in the quarry to reduce the cost of carriage.

(*b*) *Gneiss* in its typical form is practically stratified granite. It is used in masonry and also furnishes good flag-stones for flooring and paving, but is as a rule less durable than granite.

(*c*) *Mica-Schist* generally results from the denudation of granite masses, it is very pronouncedly laminated and consists of particles of mica in a slaty matrix. It varies very much in hardness, composition and durability. It is very generally found at low elevations in the Himalayas. It is inferior in quality to both granite and gneiss as a building stone.

(*d*) *Trap and basalt* both have a fine grain; which is scarcely visible in the last named. Trap is usually dark green, basalt nearly black. The former breaks up into small pieces, the latter into long prisms. They both yield good building stone, especially flags for pavements. The bluish green varieties are said to be the best, they are very hard and heavy. Trap and basalt are found very extensively in the Deccan, Western India, and the Central Provinces.

(*e*) *Sandstone* is a stratified rock consisting of grains of quartz cemented together by a matrix of silica, alumina, or lime. It is strongest when the cementing material is nearly pure silica, and weakest when it consists of alumina. Sandstones vary from a strong stone, well adapted for building purposes, to a soft one useless in construction. A freshly fractured surface of good sandstone is characterized by the sharpness and angularity of the grains, the small proportion of cement and a clear shining and translucent surface. Rounded grains and a dull surface show little durability. Colour is no guide to quality. Good sandstone should not weigh less than 130lb per cubic foot, or absorb more than 5 per cent. of its own

weight of water, and should only slightly effervesce when moistened with a dilute solution of hydrochloric acid. Sandstone resists the action of fire. Being porous it suffers by the expansion of absorbed water in freezing, if laid on edge; but if proper precautions are taken (see § 1, page 4), no harm will result. Durable sandstones form very good building materials, and they are, as a rule, easily worked. Sandstones well adapted for building purposes are largely distributed over India. They abound in both the Vindhyan and Gondwana series of rocks, and are also found in Hazaribagh and Ranchi (Chota Nagpur), Jabalpur and Cuttack. The sandstones found in the Siwaliks and Nahan hills are, with the exception of the lower beds, too soft for building purposes.

2. *Argillaceous stones:—Clay-slate* or *Slate*, as it is commonly called, is the only stone of this group which is of importance in building construction. It is a very hard and dense stratified rock, laminated at a large angle with the layers of stratification. Its colour varies from bluish-grey to purple. The qualities of good slate are compactness, smoothness, uniformity of texture, clear dark colour, lustre, and a ringing sound when struck. The majority of the Indian varieties of slate are characterized by the nearly total absence of cleavage planes which are so well defined in European varieties, and they cannot as a rule, in consequence, be split into very thin slabs of any size. They are fissile, but the planes in which they split correspond with those of lamination. Slate when procurable is eminently suited for roofing and flooring.

3. *Calcareous stones.*—Under this head *Limestone* naturally falls. A good limestone should be compact, for if porous, it will disintegrate through the direct action of the atmosphere; or through the moisture it holds expanding on freezing. It is easy to cut and shape, but generally weathers badly especially in an acid atmosphere. That containing a small percentage of silica is the best. The weight should be 140 lbs. per cubic foot. The more crystalline limestones and those containing a higher percentage of magnesium carbonate are the best. (*A. G. Hobart-Hampden.*)

To the stones mentioned above we must add *Laterite*[1] which is a term applied generically to a group of tertiary rocks which occupy an important position in the superficial Geology of India. They vary very much in composition, but the ferruginous element is common to all varieties. As a building stone laterite is easily worked, hardens on exposure, while some varieties wear well.

Boulders.—In submontane districts it is often necessary to construct buildings of boulders. If this is the case, in order to obtain strong walls, it is necessary that the masons should chip the boulders sufficiently to allow the mortar to get a good hold of them. When broken across and their flat surfaces laid upwards a good strong flooring can be made of boulders set in lime mortar.

[1] V. Ball. Economic Geology of India, 1881, pages 549 and 550

§ 6. BOMBAY PRESIDENCY—*Distribution of the more common Building stones used in Forest works.*—In *Sind*, the ordinary material used in the construction of temporary buildings is sun-dried bricks, which, owing to the absence of rain, last for a long time. Burnt bricks are used for permanent structures. In Kathiawar, limestone is chiefly used, but where trap is found it is also used. All buildings are constructed with lime mortar as lime is very cheap.

Guzerat.—In Ahmedabad, Kaira, Broach, and the greater part of Surat, all permanent works are constructed of burnt bricks set in lime mortar. In parts of Surat and in the Panch Mahals, basalt is obtainable, and, owing to the heavy rain-fall, lime mortar is used in the construction of the majority of the buildings.

Deccan.—Basalt set in lime mortar or mud is the chief material used, bricks being seldom procurable. In parts of Bijapur, Kuladgi and Belgaum excellent sandstone is obtainable. In Bijapur itself the material used is amygdaloid, while in Dharwar, parts of Belgaum, and parts of Satara laterite is procurable and largely used for buildings owing to the ease with which it can be worked. (*R. C. Wroughton.*)

MADRAS PRESIDENCY.—The principal building stone in Bellary, Anantapur, and parts of Cuddapah and Kurnool is granitic gneiss which yields a very good building stone. It cleaves into slabs of varying thickness and can be easily dressed with a hammer. The Cuddapah slab, another excellent building stone, is a metamorphosed limestone, and is quarried in slabs ½ to 5 inches thick, and is so flat and regular that near the quarries native houses are built of it without any cementing material whatever. Its transverse strength is much greater than that of granite, and it is much used for lintels over doors and windows. It is very hard, and is the best flooring material procurable.

In Nellore laterite is much used; it is soft when quarried and can easily be cut into any required shape, but hardens on exposure to the air and makes a very durable building stone. In Cuddapah a sandstone is found which can be easily worked but weathers badly. (*F. A. Lodge.*)

SECTION II.—BRICKS.

§ 7. DEFINITION OF TECHNICAL TERMS.[1]—Bricks consist of impure clay which is first of all specially prepared and then moulded into definite shapes. When the moulded bricks are simply dried in the sun, they are called *sundried* or *Kachha;* when in addition to this they are hardened by fire they are called *burnt* or *pucka.*

[1] R. L. Heinig, Deputy Conservator of Forests, Bengal, Lower Provinces.

Bricks when overburnt and vitrified in the kiln are called *Jháma*; and when underburnt and soft they are called *pilá* or *amah.* *Khoá* or *rorá* is the name given in Bengal to broken brick, whether used in concrete or for road metalling. *Pilá* is used for the foundation and casing of brick kilns and the lining of flues. In Bengal it is customary to burn those *pilá* bricks which would otherwise be wasted, in special kilns in order to obtain *Jháma.*

Burnt bricks are usually divided into three classes, *viz.*:—

1st class.—When of uniform size, with flat sides and well defined edges, thoroughly and equally burnt, hard and sound, of a deep red or copper colour, and ringing clearly when struck.

2nd class.—When fairly well burnt, and ringing clearly when struck, but somewhat uneven in shape and partly vitrified.

3rd class.—When either *Jháma* or *pilá.*

First class bricks should not absorb more that $\frac{1}{16}$th of their weight of water.

§ 8. Earth which is composed of clay and sand with a small proportion of other mineral substances, such as lime, magnesia, and iron, is suitable for making bricks. Clay is an impure silicate of alumina. Sand, if pure, consists of silica only; it is, however, generally coloured by some mineral matter, very often a salt of iron. A good brick earth should contain sufficient *flux* (a substance which has the power of promoting fusion), to fuse its constituents at a furnace heat, but not so much as to make the bricks melt at this heat, run together and become vitrified. The best brick earth contains $\frac{3}{5}$ths of silica, $\frac{1}{5}$th alumina and $\frac{1}{5}$th of iron, lime, magnesia, manganese, soda and potash. Chemical analyses are not so useful as they might be in determining the value of an earth for brick making, as they do not ordinarily show the difference between the silica which exists as sand and that combined with alumina as clay. An earth which contains one part of sand, three parts of clay, and one part of other mineral substances will make very good bricks, whereas bricks of fairly good quality can be made from earths containing as much as $\frac{4}{5}$ths by weight of sand.

Clay in excess renders bricks liable to crack in drying and to be imperfectly burnt. Sand in excess renders the bricks liable to fuse (*i. e.*, become vitrified) in burning. Lime in excess will cause the bricks to melt in the kiln and lose their shape. Lumps of limestone in brick earth are very injurious, as they swell in burning and crack the bricks; furthermore, the limestone is turned into quick-lime in the process of burning, and this slakes directly the bricks are wetted or exposed to the weather. Organic matter should also be carefully excluded as, if not completely burnt in the kiln, and it rarely is, it exudes soluble compounds which discolour plastering.

The red or copper colour of bricks is due to the presence of iron in the brick earth.

The best way to ascertain the suitability of an earth for brick-making is to make a few small bricks and to burn them in the fire, taking care to protect them from actual contact with the fuel. An examination of the resulting bricks will give a good idea of the quality of the brick earth. The suitability of earth for brick-making cannot be satisfactorily determined by mere inspection. Another way is to work up the earth to the consistency required for moulding and then test it by hand pressure. If there is too much clay, it will adhere to the fingers, but if suitable for brick-making, it will leave them clean.

In Madras, balls of brick earth[1] of different admixtures are made and exposed to the sun for three or four days, those which crack least and bind most are used for brick-making. It is often advisable to mix two or three kinds of earth so as to obtain a mixture suitable for making bricks. In places where the proportion of clay is too large, the addition of sand will materially improve the quality of the bricks obtained. *Reh* soils are utterly unsuitable for brick-making.

Fairly good bricks may be made of *black cotton soil* mixed with coal ashes. Eighty measures of this soil are put into a tank and watered copiously until it is in the form of a slip containing some kankar. The slip

[1] A. W. Lushington, Madras Presidency.

is then run through a sieve into settling tanks, where it is mixed with 90 measures of well burnt coal ashes and ground to pass through a sieve 36 meshes per square inch. This process separates the kankar. When the ashes and slip are thoroughly incorporated the mud is allowed to settle, the water drawn off, and when the mud is dry enough, bricks are made of it and pressed in screw presses. The average breaking weight of these bricks loaded in an hydraulic press on end is 10·5 cwt. per square inch. To burn from 10 to 11 thousand bricks 9" × 4½" × 2½" in a kiln it requires 600 to 650 c. ft. of green wood, measured in the stack. These bricks have been made at Warora, where coal ashes can be obtained. (*A. E. Lowrie.*)

A mechanical analysis of brick (or other) earth which is sufficient for the present purpose may be made as follows[1] :—

Take a certain weight of the earth, powder it and place it in a receptacle full of water; stir the water and then let the mud settle. When the water has become clear, pour it off. Repeat this operation half a dozen times with *plenty* of water. Then dry and weigh the residue. The difference between the weight now found and the original weight is the weight of lime which has been dissolved. (N. B.—Hot water with a little acid hastens this operation). Put the residue back into the receptacle, add water and stir, pour off the muddy water and repeat this operation till the water remains clear. The residue will be sand, the clay having been removed in suspension.

§ 9. PREPARATION OF BRICK EARTH.—The surface of the soil from which the clay is to be obtained is first stripped off. The sub-soil is then dug up and all stones, roots, and objectionable organic matter carefully removed. The clay is then carefully and thoroughly *tempered.* The process of tempering consists of digging the brick earth over and adding water until it is reduced to a homogeneous consistency and no lumps are perceptible. The earth should be worked for two or three days, and during that time will absorb about half its bulk of water.

When practicable the earth should be dug up and left exposed to the action of the atmosphere for two or three months, before being tempered and moulded into bricks, so as to allow of its becoming thoroughly disintegrated. In order to ensure this, it should be spread out in a fairly thin layer and turned over occasionally so as to expose all parts of it equally to the air.

[1] F. A. Lodge, Madras Presidency.

When a large number of bricks are to be made, a pugmill is usually employed for the tempering of the brick earth, and in this case the sub-soil is dug up before the rains, and allowed to weather throughout the whole period of the monsoon. At the close of the rains when brick-making commences, it is again dug up, placed on level ground and worked with hoes for two or three days. On the day before the manufacture of bricks begins, as much of this soil as is required for one day's consumption is well watered and hoed up. The next day the soil so prepared is placed in the *pugmill* and on issuing from it the brick earth is ready for the moulder.

The mill in which the brick earth is tempered consists of a conical vessel of wrought iron[1] 3 feet 6 inches high, sunk 2½ feet into the earth. It is provided with a vertical revolving shaft to which are attached cutting knives. The knives are fixed at right angles to the vertical shaft and their blades inclined at an angle of 45° to the vertical, so that the clay, besides being cut up and the lumps contained in it broken, is gradually forced out of an aperture at the base of the mill. The pugmill when full can be easily turned by a pair of bullocks. Brick earth after being tempered should neither be too stiff nor too loose. If it is too stiff the resulting bricks will crack in drying, if too loose (which would result from too large a proportion of sand), they will fuse in burning.

§ 10. MOULDING BRICKS.—After the brick earth has been properly tempered, the next thing to be done is to mould it into the required shape. The moulds used in different localities vary slightly in form. A mould consists essentially of a wooden frame rectangular in section, two sides of which project to form handles. Thin strips of hoop iron are screwed on to the edges of the frame to prevent their being worn out quickly.

[1] Memorandum on the system of brick-making at Akra.—Bengal Secretariat Press, 1884.

FIG. 2.

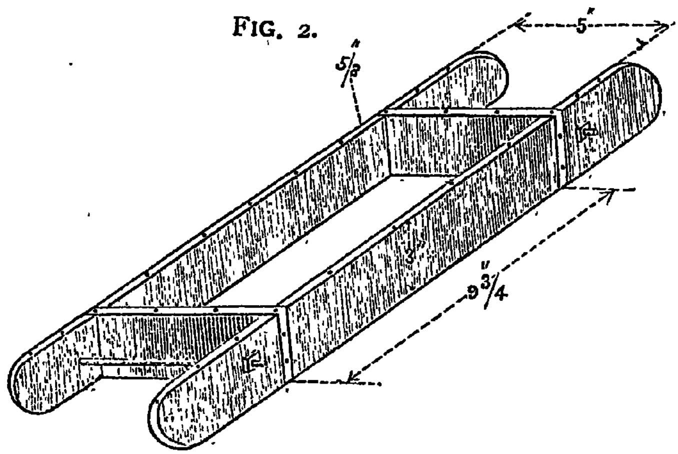


Figure 2 is a dimensioned sketch of a brick mould as used in the Dehra Dún district.

FIG. 3.

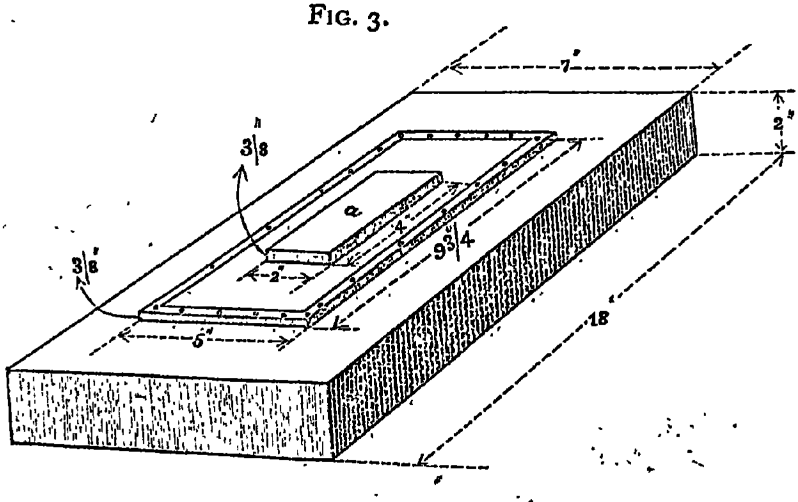


Figure 3 shows a block on which bricks are moulded. The edges of the mould and block are bound with a thin iron strap screwed on to the wood. The projection a *forms the frog of the brick.*

The mould should be made of some hard tough wood which seasons well and does not warp or change its form, such as sissoo (*Dalbergia Sissoo*) and should be made from $\frac{1}{10}$—$\frac{1}{12}$ (*Rankine*) to $\frac{1}{12}$—$\frac{1}{20}$ (*Roorkee Treatise*) larger than the required

size of the burnt brick. A mould $12\frac{1}{2} \times 6 \times 2\frac{3}{4}$ inches will give a burnt brick $11\frac{1}{2} \times 5\frac{1}{2} \times 2\frac{1}{2}$ inches. Bricks of the ordinary English size ($8\frac{3}{4} \times 4\frac{1}{4} \times 2\frac{1}{2}$ inches) are now coming into general use in India.

The greatest shrinkage in bricks occurs during the process of drying preparatory to being burnt. Bricks shrink very little during the process of burning. The amount of shrinkage depends upon the wetness of the brick earth and also upon the proportion of clay that it contains.[1]

The mould and the block may be made in two separate pieces *as shown in figures 2 and 3, or may be made in one piece.*

In Bengal, brick moulds are made of wrought iron $\frac{3}{16}$ ths of an inch thick. Their inside dimensions are $10\frac{1}{4}'' \times 5\frac{1}{8}'' \times 3\frac{1}{8}''$, the size of the burnt bricks being $9\frac{1}{4}'' \times 4\frac{1}{2}'' \times 2\frac{3}{4}''$. The heads of the mould are made of the best plate iron, bent at right angles to form the joint. The joints are rivetted. The ears of the mould project $\frac{3}{4}$ths of an inch. The strike used with these moulds is of wood. (*R. L. Heinig.*)

The bricks may be moulded on the ground or upon a block of wood, the bottom of which is cut to fit the mould; there is a raised projection on the block which forms the indentation or *frog*, in the bottom of the brick. The mould, before being used, is either sprinkled with sand, or placed in water, so as to prevent the brick earth from sticking to it. After this has been done, a lump of well tempered brick earth is thrown forcibly into the mould so as to fill it completely; the brick earth should be thoroughly pressed into the corners of the mould so as to completely fill them. The superfluous earth is removed by means of a metal straight-edge, called a *strike*, or with a piece of wire.

The clay which is thrown into the mould should be in a plastic state so as to accommodate itself to the shape of the mould, and must neither be too dry nor too wet; if too dry, it will not fill the mould properly, and if too wet, the brick may lose its shape while drying.

If the bricks are moulded on the ground, the latter, after it has been levelled, must be well sanded. When a brick has been moulded, the mould is gently lifted up leaving the brick on the ground. The same process is repeated with each

[1] R. H. Hodges, P. W. D. (Railway construction branch).

brick, the mould being moved each time a few inches to one side. The moulding of bricks on the ground cannot be recommended.

When the bricks are moulded on a block, the moulder, after removing the superfluous clay with the *strike* and smoothing the surface of the brick, turns the mould over on its side and places a piece of thin plank called the *pallette board* on the under side of the brick. Supporting the pallette board with one hand, the moulder turns the mould upright again and places it on a table on one side of the block. He then lifts the mould carefully, leaving the moulded brick upon the pallette board.

When the bricks are removed to the drying ground, a second pallette board is placed on the upper surface of the brick, which is then lifted between both boards and placed on edge on the drying ground. The pallette boards are then removed. Bricks cannot be made in rainy weather.

§ 11. Process of drying bricks.—As soon as the bricks are sufficiently firm to allow of their being handled, they are removed to the drying ground, and placed in loose stacks so as to allow the air to circulate freely and equally around them. The ground on which the bricks are placed should be sanded and raised slightly so as to be out of reach of rain-water. Bricks take about 8 days to dry in the cold and about 3 in the hot weather. Shelters of bamboo and grass should be provided for use in case of rain, as a sundried brick when once thoroughly soaked will be useless although it may have retained its shape and become dry again. The bricks should not be allowed to dry too quickly; in the Madras Presidency it is customary to use a light thatching of straw to protect the moulded bricks from the sun as well as from the rain.

When a large number of bricks are to be made, the drying ground may be first prepared by the formation of raised banks called *hacks*, well trodden, rolled, neatly dressed, and then strewn with fine sand or ashes. The hacks should run in parallel rows about 6 feet apart. They are $3\frac{1}{2}$ feet wide at the base, $2\frac{1}{2}$ feet at the top and 6 inches high. When rain falls, the upper layers of the bricks on the hacks are protected by matting or

grass shades, while the raised banks protect the lower layers from injury by the accumulation of water. The moulded bricks are placed in two vertical series up to a height of 6 rows, one above the other, and left for two or three days until sufficiently hard to be handled. They are then opened out so as to leave 1½ inches space between the bricks in order that they may dry rapidly by the free circulation of air. When thoroughly dry the bricks are removed to the clamp or kiln. (*R. L. Heinig*).

The greatest shrinkage in bricks occurs during the process of drying, during the burning they shrink but little. The amount of shrinkage depends chiefly upon the proportion of clay in the brick earth and on the amount of water added during the process of tempering (*R. N. Hodges, Public Works Department*).

§ 12. BURNING.—When a sufficient number of bricks have been moulded and sundried, they should be burnt. Bricks may be burnt either in a *kiln* or a *clamp*.

The Indian clamp is an arrangement for burning bricks in the open air and is chiefly used in Northern India and the Punjab. In a clamp, the bricks and fuel are laid in alternate layers, the former in courses of five or six bricks, the latter in layers of from 2½ to 3 feet in thickness.

The plan of the clamp is usually triangular. The floor is a plane surface which is usually inclined at an angle of about 15° with the horizon. The lowest point of the base of the clamp is one of the angular points of the triangular-shaped floor. The clamp is lighted at the lowest point of the base and the fire is led up through the different layers in the clamp. The object to be aimed at in burning bricks is to heat the bricks *equally* all through the clamp, though in practice it is rarely possible to attain this end completely.

FIG. 4.

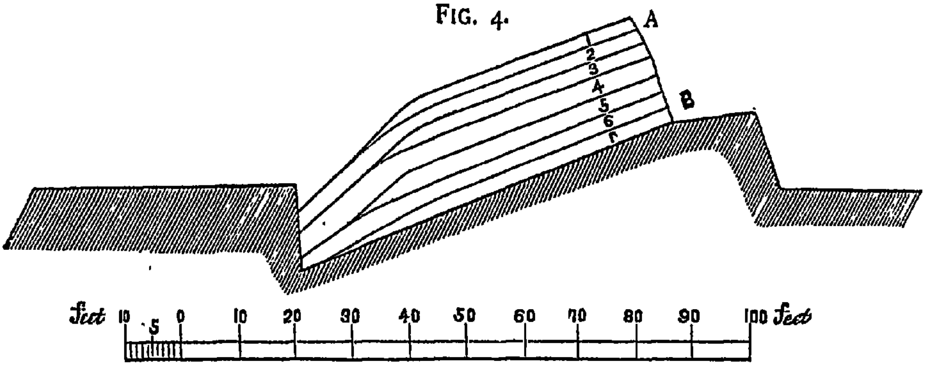


Figure No. 4 shows a vertical section through a brick clamp which is partly burnt. 1, 3, 5, and 7 are layers of fuel; 1 is 1½ feet thick, the others are each 3 feet thick. 2, 4, 6 are layers of bricks, 2 is 2½ feet thick, the other two are 3 feet thick. The layers of fuel and brick were originally inclined at an angle of 20 degrees with the horizon.

The measurements given above were taken from a brick clamp at Dehra Dún.

The fuel generally used in Indian clamps consists of manure (*khâtt*), dried cowdung (*úpla*), litter and miscellaneous town sweepings (*kúra*), sometimes a little wood is used in the lower layers. The fuel described above burns more slowly and evenly than wood by itself, and is for this reason considered preferable, so far as the *clamp* method of brick-burning is concerned. Wood is said to burn too quickly, with the result that the bricks are very unequally burnt; consequently a clamp is not generally suitable for works under construction out in the forest.

The end of the clamp (A B, figure 4) which is furthest removed from the point at which the kiln is lit, is nearly vertical. The thickness of the layers of fuel diminishes slightly towards the top of the clamp, the upper layer is 1½ feet thick and covered with ashes to keep in the heat. The sides of the kiln are usually closed by rubbish, but the upper end (AB) should be perfectly open.

Burnt bricks may be removed from the lower part of the kiln as soon as they are cool enough to handle, if they are wanted. If the bricks are not wanted immediately, the clamp is allowed to burn out and the bricks are removed as they are sold.

The cost of moulding and stacking bricks in clamps varies with the locality; in Dehra the cost is Rs. 2, in the Kistna District, Madars, from Re. 1-4 to Rs. 2-8 per thousand. In this method of burning bricks there is considerable loss, as many bricks are broken or bent by unequal sinking in the kiln, as the fuel is consumed. Some of the bricks are overburnt and usually a considerable proportion are under-burnt; many are bent, probably partly owing to their being put in the kiln before they are properly dry. These irregularities in burning are due to the unequal distribution of heat through the clamp; and are especially noticeable in the case of large clamps.

§ 13. THE ENGLISH CLAMP consists of a stack of *raw* (sundried) bricks, built over a system of flues, roughly formed and leading through the clamp from the fire-holes at which the fuel is introduced.

In England, *breeze* (small ashes and cinders) is introduced between the different layers of bricks, and the fire-holes in which are the faggots used for lighting the kiln are very small. In India, however, coal is very rarely (in forest works) obtainable, and wood fuel is almost exclusively used; in this case no fuel is placed between the different layers of bricks, and the flues and fire-holes are made very much larger and are kept full of fuel until the stack of bricks is burnt right through.

The method of arranging the bricks in the English clamp is called *setting*, and must be very carefully done, so as to allow of the bricks in the clamp being heated as equally as possible. The following description of setting the bricks in an English clamp is adapted from the Roorkee Treatise on Civil Engineering in India, Vol. 1, page 44 (3rd edition, 1878):—"The bottom" "of the clamp is laid in regular rows of two or three bricks wide" "with an interval of two bricks between each, and these rows" "form, when built up, so many walls extending lengthwise of" "the clamp and running right through it. They are built at" "least 6 or 8 courses high, so as to give the stack of bricks" "the appearance shown in the figure (fig. 5)."

FIG. 5.

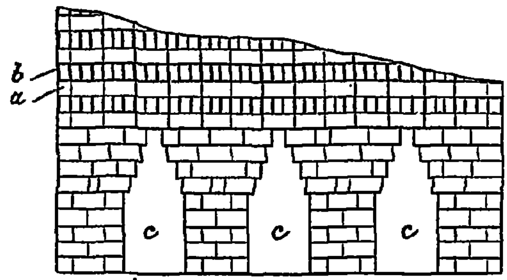


Fig. 5 is an end elevation of an English kiln, to show the method in which the bricks are set so as to form the flues c. c. c. *After the flues are made, the bricks are laid in courses alternately lengthwise* a. *and endwise* b., *the dark thick lines are spaces left between the bricks to allow the heated air and flames to pass up between the bricks.—(From the Roorkee Treatise on Civil Engineering in India.)*

"These rows of bricks form the *flue* walls and are con-" "structed of sundried bricks. The intervals between the" "walls are laid first with shavings or brushwood, or any-" "thing that will kindle easily, then with larger brushwood" "cut into short lengths, so that it may pack in a compact" "manner, and lastly, with logs of split wood. This done," "the *overspanning* or formation of the arches over the open-" "ings between the walls of bricks is commenced. For this" "purpose every course of bricks is made to extend 1½ inches" "beyond the course immediately below it for 5 courses in" "height, taking care to *back up, i.e.* fill up with bricks against" "the over-spanners. An equal number of courses on the" "opposite side of the arch is then set in the same way, and" "thus the arch is formed. The arches must be carefully con-" "structed as if they fall in, the fire may be extinguished," "or many of the bricks above the arch broken. The in-" "termediate spaces between the arches are then filled up so" "as to bring the whole upper surface of the clamp to the same" "level, and then the setting of the kiln proceeds regularly" "until it attains its full height. In setting the bricks in the" "clamp not only in its body but in the arches also, the ends"

"of the bricks touch each other, but narrow spaces are left" "between the sides of every brick for the fire to play" "through. This is done by placing the bricks on their edges," "following what is called by brick-makers the rule of "three" "upon three" and reversing the direction of each course as" "shown in fig. 6."

FIG. 6.

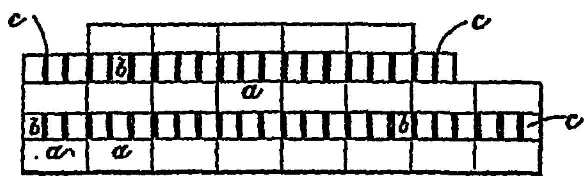


Fig. 6 is an elevation to show in detail how the alternate courses of bricks are arranged in an English kiln or clamp; a. a. a. *are bricks laid lengthwise in one course, while in the next course, the bricks are arranged endwise as* b. b. b., *the dark portions* c. c. c. *represent spaces between the bricks.—(From the Roorkee Treatise on Civil Engineering in India.)*

"The clamp being completed the top course is laid with" "flat bricks so disposed that one brick covers part of three" "others."

The clamps which Forest officers may require to make will generally be small and the flues should be arranged crosswise instead of lengthwise, so as to ensure a more equal burning.

The arched spaces formed when the bricks are set in the clamp serve as *flues*, in which the fuel is placed. The fuel can be pushed in from either side of the clamp. The fuel used is generally wood, and if possible hard wood, such as that yielded by sâl (*Shorea robusta*), babûl (*Acacia arabica*), sissoo (*Dalbergia Sissoo*), khair (*Acacia Catechu*) and other trees of a similar structure, should be used. In South India[1] the best wood for brick burning is said to be Tamarind (*Tamarindus indica*)[2] which is preferred to any of those mentioned above. The

[1] A. W. Lushington.
[2] Vernacular Imli.

flues are then filled with wood and lighted and are at first allowed to smoulder rather than burn; this gradually causes the moisture in the kiln to evaporate. When the colour of the smoke given off changes from a light to a dark colour, the fires should be allowed to burn up briskly. The rate of burning may be regulated by partially stopping or opening the fire-holes, or by covering up the top of the clamp, as required, with ashes or earth. The progress of the burning of the clamp can only be seen at night. The fires are kept up until the top layer of bricks is thoroughly burnt. The fire-holes are then closed and the clamp allowed to cool very gradually. When thoroughly cool the bricks can be removed and sorted.

In the Darjeeling district the ordinary method of burning bricks in clamps is as follows. The sundried bricks are stacked as described above, and the outside of the stack of sundried bricks is covered with a layer of clay. The top of the stack of bricks is covered with a layer of dry leaves and earth. The fires are lit in the flues, wood being generally used, and the fires are kept up in the manner described above. When the fire has reached the top layer of bricks and has burnt through this layer, the dry leaves are lit, and in burning give off smoke, the fires are kept up for a short time longer to ensure the upper layer being properly burnt and are then allowed to go out by stopping the supply of fuel and closing the fire-holes. The ends and sides of the clamp are smeared with clay in order to keep in the heat as much as possible.

§ 14. THE ENGLISH BRICK KILN.—The form of kiln which is ordinarily used where only a small number of bricks are required is known as *the English kiln*. It consists of a rectangular building, open at the top, and having wide doorways at the either end. The side walls are often built of old bricks set in clay. Several openings are left in these walls opposite to each other to serve as fire-holes. The top of the kiln may have a temporary covering to protect the bricks from the weather. The arrangement of the bricks in the kiln is the same as has been already described in connection with the English clamp (see pages 20 to 22). When the kiln is filled, the end doorways through which the bricks are brought into the kiln are bricked up and the fires in the flues lit. The process of burning is regulated as in the case of the English clamp. A kiln,

60 ft. long, 11 ft. wide and 12 ft. high[1] (internal measurements) will contain about 80,000 bricks. The fire-holes should be 3 ft. apart. The bricks in the centre of the kiln are generally well burnt. Those at the bottom will probably be very hard and partially vitrified, while those at the top of the kiln will be insufficiently burnt.

Where large quantities of bricks are required—the following advantages are claimed for kiln-burnt bricks:—

(1) The bricks are more uniform in quality.
(2) The sundried bricks need not be left so long to dry before they are placed in the kiln.
(3) The percentage of properly burnt bricks is much larger.
(4) There is a saving of time, which counterbalances the increased consumption of fuel.

Where large quantities of bricks are required *Bull's trench kilns* are very generally used in India, as they not only effect a very considerable saving in fuel, but also turn out a very much larger percentage, often as much as 80 per cent. of well burnt bricks. The principle of construction and method of working of these kilns are given in Appendix No. I.

§ 15. CHARACTERISTICS OF GOOD BRICKS.—The qualities of burnt bricks may be considered under the following heads[2]:—

(1) *Degree of burning.*—A well burnt brick will neither be brittle nor absorb much water, and will stand under water without harm for any length of time. An overburnt brick is brittle, and an underburnt one is affected by exposure to the atmosphere, and under water (as in the pier of a bridge) simply disintegrates.

(2) *Freedom from flaws and lumps.*—Good building bricks should be free from cracks, flaws, stones or lumps of any kind. Lumps of lime are specially dangerous.

[1] Notes on Building Construction, Part III, Materials, page 99 (2nd Edition), Rivington's, London, 1889.

[2] Notes on Building Construction, Part III, Materials, pages 110 and 111 (2nd Edition).

(3) *Shape and Surface.*—Bricks of good quality should be regular in shape and uniform in size. Their edges should be square, straight and sharply defined, and their surfaces even, neither hollow nor too smooth.

(4) *Absorption of water.*—The proportion, by weight, of water absorbed by a brick is a very good indication of its quality. Unburnt bricks absorb a large proportion of water and are in consequence not durable when exposed to the air. The average absorption of water by bricks is about $\frac{1}{6}$th of their weight. Highly vitrified, that is, overburnt, bricks only absorb $\frac{1}{12}$th to $\frac{1}{16}$th of their weight of water.

(5) *Texture.*—A thoroughly burnt brick will emit a metallic ring when struck against another brick; unburnt, insufficiently burnt, and unsound bricks do not ring. Overburnt bricks also emit a metallic ring. Bricks should be so hard that the finger nail is unable to scratch or make a mark on them.

(6) *Colour.*—The colour of bricks depends upon the chemical composition of the brick earth used and the degree of burning to which they have been subjected. If iron were entirely absent, the bricks would be nearly white. Iron produces a light yellow, orange or red colour according to the quantity in which it is present. Bricks of a deep red colour are usually good; the colour should be uniform throughout. Underburnt bricks have usually a light red or yellowish tinge; overburnt bricks are darker in colour and are more brittle than properly burnt ones.

§ 16. SIZE OF BRICKS.—The size of ordinary bricks in the neighbourhood of London is 9 inches long, $4\frac{1}{4}$ inches wide, and $2\frac{1}{2}$ inches thick.

In India the size of bricks varies considerably. The sizes used in Northern India by the Public Works Department are now—

$$9\tfrac{3}{4} \times 4\tfrac{5}{8} \times 2\tfrac{7}{8} \text{ inches,}$$

and

$$9 \times 4\tfrac{1}{2} \times 2\tfrac{3}{4} \text{ inches.}$$

A very large brick is inconvenient for an ordinary man to grasp. In order to construct good brickwork, it is important that the

length of each brick should just exceed twice its breadth by the thickness of a mortar joint, in order that two *headers* (*i.e.*, bricks placed with their length parallel to the thickness of the wall) with a mortar joint may cover one *stretcher* (*i. e.*, a brick placed with its length parallel to the length of the wall).

§ 17. USE OF BRICKS.—Bricks are used chiefly in the construction of the walls of buildings, bridges and well-linings, and more rarely in retaining walls. They may be introduced into masonry for the construction of those parts which require more careful work, such as for arches, doorways, around window openings; at the corners of buildings, and also as *string courses* (*i.e.*, carefully built courses introduced into common rubble masonry). They are also used in the construction of floors, for which purpose, if carefully laid on a good foundation, they are well adapted. Occasionally they have to be moulded into special shapes, as for example in some kinds of arches, and for well-linings. Where good stone is procurable, within a measurable distance, bricks are not used, as brick-work costs considerably more than the commoner kinds of masonry.

SECTION III.—TILES.

§ 18. Tiles are commonly used either for making roofs, for the construction of floors and for drains. Those used for the first two purposes mentioned will be considered here. Tiles should be made from *stiffer*, *i.e.*, purer clay than is necessary for the manufacture of bricks; blue clay being especially suitable. Stiff clay suitable for tile-making is often found below that which is fit for brick-making. The earth from which tiles are made should contain no sand, ashes, straw, or other impurities, and must be most carefully *tempered*. If the clay is not sufficiently stiff, the resulting tiles will be porous, light and brittle, and will consequently be unsuitable for the construction of roofs or floors. The kinds of tiles commonly used for roofing purposes are—(1) Pot tiles, (2) Pan tiles, (3) Flat tiles, (4) S tiles.

Pot tiles are very commonly used for the construction of roofs. One end is slightly broader than the other as is shown

in figure 7, which represents the pot tile commonly made in the Dehra Dún District.

FIG. 7.

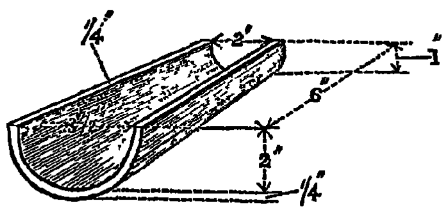


Figure 7 is a dimensioned sketch of a pot tile.

Pot tiles are commonly turned on a potter's wheel. A hollow truncated cone of clay, of the required dimensions is first made. Two lines are scored down the outside of this tube of clay lengthwise, so as to divide into two equal portions. After the tiles have been burnt they can be split along the scored lines by tapping them sharply with a trowel or mason's axe. One tube of clay thus makes two pot tiles. The manufacture of pot tiles of superior quality is described at page 28 *et seq*.

Pan tiles are flat tiles, the edges of which are slightly curved and bent up: they are also used for the construction of roofs, usually in conjunction with pot tiles. One end of the pan tile is broader than the other.

FIG. 8.

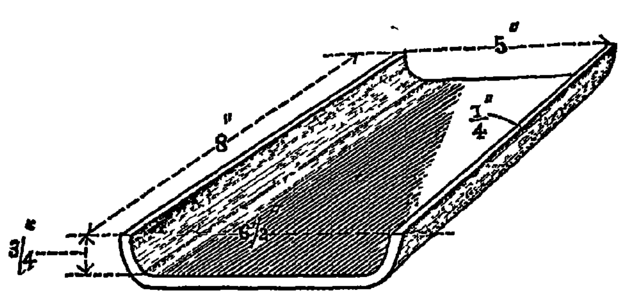


Figure 8 represents the pan tile commonly made in the Dehra Dún District.

In the Dehra Dún District the length of a pan tile is about 8 inches, the width at the larger end is 6½ inches, and at the smaller end 5 inches. The turned-up portions of the sides are about ¾ of an inch deep. The thickness of all the tiles above mentioned is usually about ¼ of an inch. Pan tiles may have two holes made near one end to allow of their being fastened to the roof timbers.

Flat tiles are usually rectangular in shape. Those used for roofing purposes usually have two holes bored near one end to allow of their being nailed on to the roof timbers. Sometimes the holes are omitted, and two little projections at the back of the tile are substituted for them.

FIG. 9.

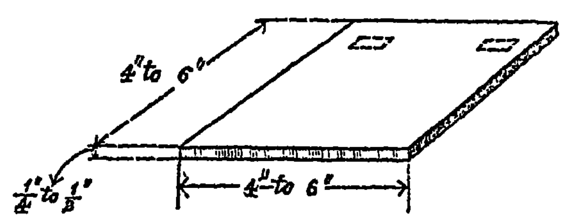


Figure 9 is a dimensioned sketch of a flat tile for roofing purposes, the projections at the back of the tile are shown in dotted lines.

Flat tiles used for flooring, and also in the construction of terraced roofs are made much larger than those used in the construction of pent roofs. They are often as much as 1½ to 2 ft. square, and from 1 to 2 in. thick.

S. *tiles* if sufficiently heavy, will form a good water-tight roof. Their shape is that of a flattened S laid on its side. The tiles are laid so as to overlap. The objection to them is the difficulty of repairing the roof if any get broken.

§ 19. MANUFACTURE OF TILES.—The quality of tiles depends very largely upon that of the clay from which they are made. The tempering of the clay must be most carefully attended to, all hard lumps and stones being removed and the clay reduced to the same consistency throughout. When the clay has

been thoroughly tempered it is either turned on a potter's wheel or moulded. In the latter case a *pattern* of the shape and size of the tile required should be given to the workmen and a wooden mould of the required dimensions be prepared from it.

FIG. 10.

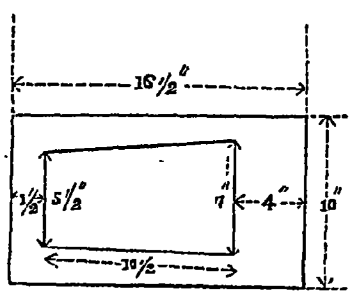


FIG 11.

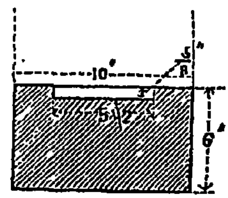


Figure 10 shows a dimensioned plan of a mould for making pot or pan tiles. Scale = $\frac{1}{12}$.

Figure 11 is a section through the same mould. Scale = $\frac{1}{12}$. (adapted from the Roorkee Treatise).

The actual shape of the mould depends upon the surface dimensions of the tiles required. If flat tiles are wanted, the mould should be made a little larger than the actual dimensions of the required tiles. If pot or pan tiles are wanted, the mould should be dimensioned so as to make a tile of the same size as the pot or pan tile, as the case may be, when flattened out.

The mould is sprinkled with wood-ashes or brick-dust to prevent the clay adhering to it. The tile-maker then takes a piece of tempered clay sufficiently large to fill the mould, throws it violently into the mould, and proceeds to work it thoroughly into the four corners. The superfluous clay is cut off by a piece of wire. A flat piece of wood (*the strike*) or a ruler is then passed backwards and forwards over the clay, until the surface is quite smooth, and the tile is lifted out of the mould by placing the extended hand on it. The moulded tiles are then placed in small heaps of about twenty.

The above process is the same for flat, pan or pot tiles. In the case of pan tiles the edges of the tile are carefully turned

down over a rectangular block of wood. Pot tiles are given the required shape by being placed on a second mould (called the *horse*) which is shown in figure 12.

The horse consists of a piece of wood constructed so as to give the tile its required shape. The horse is first sprinkled with sand, the moulded tile placed on it and bent into the

FIG. 12.

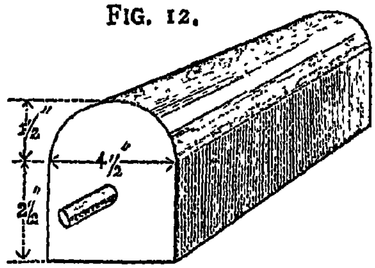


Figure 12 is the sketch of a horse used for moulding pot tiles.

required shape. The back of the tile is then moistened with water in order to allow of its being removed from the horse. After a period of from five or six hours, by which time the tiles are firm enough to be lent up against a wall without losing their shape, they are rehorsed, trimmed, and the ashes cleaned off them, and are allowed to dry for six hours more, after which time they are ready for burning. The moulded tiles should be placed in sheds to dry, in order to prevent them from cracking and losing their shape.

Tiles are burnt in a kiln, similar to that in which bricks are burnt; a few layers of bricks should be put over the flues, and then the tiles to be burnt are placed on them edgeways as close together as possible. When the kiln is full the doorways are bricked up, the top covered with a loose layer of tiles, and the fires lighted. Tiles may be burnt with bricks in any flame or trench kiln. The tiles are at first gently heated until the steam disappears from the top of the kiln. The flues are then filled with fuel and the tiles brought to a red heat. The fires are then allowed to burn low, no more fuel being added for six hours. The flues are then replenished with fuel, and the tiles raised

to a white heat, and kept at that temperature for six hours. The fires are then slackened for six hours, and raised again to a white heat for four hours. The flues are then filled with fuel, the fire-holes stopped, and the kiln allowed to burn out. When cool the tiles are removed. The kilns should be sheltered to the windward, or the tiles on that side may be underburnt.

One cubic yard of well-tempered clay will make about 1,000 pan tiles $10\frac{1}{2}$ inches long by $6\frac{1}{2}$ inches wide at the larger end by $\frac{5}{8}$ inch thick.

SECTION IV.—EARTH, GRASS AND BAMBOOS.

§ 20. EARTH is largely used in India for small or temporary constructions, especially in forest works where everything has to be built as economically as possible, and is in many cases of a very temporary nature. It is also largely used by the inhabitants of the hills and plains in the construction of their own houses, and they consequently thoroughly understand its use. Earth which is suitable for brick-making, *i.e.*, which has a large proportion of clay in its composition, is best suited for the construction of walls. Practically, however, in the majority of cases the best earth which is found near the site chosen for the proposed building is used, in order to save expense.

In Central India, *Pandri matti* (white earth found on the sites of old villages or forts)—is the best earth procurable for the construction of earth walls, and will stand exposure to the weather for many years. Earth from ant-hills is recommended for mud plaster, as white ants are believed never to attack plaster prepared of this earth. (*C. Bagshawe.*)

In Assam, *Ikra* (*Saccharum* sp.), a reed, is much used for the walls of temporary forest structures, and when covered with sand and lime plaster in wooden panels, it makes a very cheap and at the same time strong and durable wall. When *Ikra* is not procurable, split bamboo is often used instead, but is not so satisfactory. (*A. Smythies.*)

In Burma, temporary buildings, such as are commonly built

of earth in other parts of India, would be constructed entirely of bamboos.

In many parts of India temporary guards' huts, fire patrols' huts and stables are built entirely of grass fastened to a wooden frame-work, the walls as well as the roofs being made of this material.

§ 21. Earth for building purposes may be prepared in two ways. Water may be added to the earth until it forms a stiff pasty mass, and the wall constructed of large lumps of earth thus prepared, so that when dry, it will consolidate into one compact mass. Or a stiff mud may be made of the earth, and the wall, with the aid of rough moulds, built in layers with this stiff mud, well pressed down by the hands or feet. In dry weather, the layers soon dry sufficiently to allow of another layer being added. When completed the walls should be trimmed and plastered with clayey earth.

Mud walling of this nature should taper slightly. The width of the base of a wall 8 ft. high should be 2½ ft.

Walls constructed in this manner, if made of good clay in the dry weather, and especially if plastered or whitewashed, will stand a great deal of exposure to rain.

A better way of preparing earth for the construction of walls is to form sun-dried bricks from the earth and to construct the walls of such bricks set in mud mortar. The bricks should be made to break joint one with one another, so that the joints between the bricks in two consecutive layers shall not be in one and the same vertical straight line. The entry of water into the top of the wall must be most carefully guarded against. This may be done by placing one or two courses of burnt bricks set in mud mortar on the top of the walls. Walls constructed in any of the ways mentioned in this section will not bear a heavy roof.

SECTION V.—LIME.

§ 22. SOURCES OF LIME.—Lime may be obtained from kankar, limestone, sea-shells and coral. *Limestone* is a term applied

to any stone, which consists chiefly of calcium carbonate. Limestones differ much in chemical composition, texture, hardness, and other physical properties. If the limestone contains a large proportion of magnesium carbonate it is called *dolomite*; if clay is present in considerable quantities it is called *marl*. If the proportion of clay is excessive the limestone becomes useless as a source of lime. Iron, silica, and other minerals are usually found combined with calcium carbonate in limestones.

The chief sources from which lime is obtained in India are—

(1) kankar,
(2) massive limestone and deposits resulting from it,
(3) limestone boulders,
(4) sea-shells and coral,
(5) incrustations of calcium carbonate.

(1). *Kankar* is a concretionary form of carbonate of lime, usually occurring in the form of small nodules, in the alluvial deposits of India. The nodules are of irregular shape, varying in size from half an inch to 3 or 4 inches in diameter. They are composed of carbonate of lime inside and a mixture of carbonate of lime and clay outside. Kankar is sometimes found in thick beds in alluvial deposits and filling up cracks in such deposits and in older rocks. Kankar is probably formed by deposition from water containing carbonate of lime in suspension or solution. Its composition varies very much even in the same deposit; it usually contains from 50 to 75 per cent. of lime, 10 to 30 per cent. of clay, besides other minerals. The resulting lime necessarily varies in quality.

(2). *Massive limestone* consists of carbonate of lime in a more or less pure state, but differing considerably in physical structure. The term, so far as the production of lime is concerned, includes marble, crystalline limestones, dolomites and marls. In India the deposits of massive limestone are usually fairly pure and furnish lime of a good quality. Formations resulting from the denudation of these massive deposits usually contain lime of varying quality.

(3). *Limestone boulders* are collected in the beds of streams which rise in hills containing massive deposits of limestone. The lime obtained from this source also is variable in quality.

(4). *Sea-shells and coral.*—Sea-shells form the principal source of lime in the Madras Presidency in districts bordering on the sea, as well as in the Sunderbuns and other localities. The lime obtained from this source is usually of fine quality.

(5). *Incrustations of calcium carbonate* called *tufa* are formed by the deposition of carbonate of lime from water, in which it has been held in suspension owing to the presence of carbonic acid gas. Such deposits may serve as a source of lime when the rocks from which they have originated contain too small a proportion of calcium carbonate themselves to yield lime, but occasionally, as at Chemar Khan (near Naini Tál) they occur in large masses and yield very pure white lime. Such incrustations are essentially local in their distribution.

§ 23. TESTS FOR LIMESTONE.—If dilute hydrochloric acid be poured upon a piece of limestone rock, a brisk effervescence will take place, the limestone being dissolved. The carbonate of calcium is converted into a chloride and carbonic acid gas given off. The clay and sand which may form part of limestone are insoluble in hydrochloric acid. The purity of the limestone under examination may be roughly determined by noticing what percentage (by weight) of the specimen is soluble in the dilute acid. Limestone is a fairly soft rock and can be easily scratched with a knife, whereas quartz, which it sometimes resembles, is much heavier and harder, and cannot be scratched with a knife.

The natives of the Dún are very expert at distinguishing limestone pebbles from the other pebbles which are found in the beds of the streams. They can tell a piece of limestone by its weight, colour and general appearance, and if in doubt they strike the pebble against some other, and if a smell like sulphur is emitted, they are led to conclude that the doubtful pebble is limestone.

§ 24. MANUFACTURE OF LIME.—Lime is produced from limestone and other calcareous substances by the process of

calcination. In this process the carbonic acid gas and water are driven off and an oxide of calcium, *quicklime*, remains. If water is added to this substance a hydrous oxide is formed which is *slaked lime.*

When lime is mixed with a definite volume of water it hardens, and is then said to *set.* This hardening is due to the absorption of carbonic acid gas to form calcium carbonate, and the giving off of water. Lime is said to be more or less *hydraulic* according to the extent and rapidity with which the paste made from quicklime or mortar, will set under water or in the absence of air.

The process by which lime is obtained from limestone by calcination is commonly called *burning.* Lime may be burnt in—

(1) an intermittent kiln,
(2) a continuous kiln.

In an *intermittent kiln,* wood and lime are placed in alternate layers, and fire is led through the whole mass. When all the wood has been consumed the kiln is allowed to cool and the lime removed. When more lime is required the whole kiln is refilled and the process repeated.

In a *continuous* kiln, alternate layers of fuel and limestone are placed in position and the kiln lit from below, as the lower layers of fuel are consumed and the limestone converted into lime, the upper layers sink and more limestone and fuel are added at the top, while the lime and refuse is drawn off at an opening provided for this purpose at the base of the kiln. This process of replenishing the kiln can be continued as long as lime is required; the fire need never be allowed to go out; limestone and fuel can be added at the top of the kiln as the lime is withdrawn from its base.

In Northern India the best wood fuel for lime burning is yielded by Sâl (*Shorea robusta*), Khair (*Acacia Catechu*), and species of *Zizyphus.* In Southern India, Tamarind (*Tamarindus indica*) and Babul (*Acacia arabica*) are considered to be the best. The wood should be green, as it then burns more slowly.

§ 25. INTERMITTENT KILNS.—The fuel used in India for lime burning depends upon the character of the source of lime

available. Coal or wood is generally used when massive limestone is burnt. In Madras, for burning shell-lime, charcoal, dried palm leaves, grass and dried cowdung are used.

The shape of the kilns used by natives in different parts of India varies considerably, but they generally agree in being of an intermittent nature.

The walls of the kiln should in any case be thick so as to prevent the radiation of heat and to obtain the greatest uniform heat possible with the smallest expenditure of fuel.

Every time before lime is burnt in an intermittent kiln the interior and exterior (if necessary) surfaces should be carefully plastered with cowdung and clay mixed, and cracks in the wall, if any exist, properly filled up.

One native method is to burn lime without any kiln by placing limestone and dried cowdung in alternate layers in a heap, covering the heap with mud and then firing it. This is a very simple and cheap method where only small quantities of lime are required, but is at the same time a very wasteful one.

Figures 13 and 14 show the section and plan of the common form of intermittent lime kiln now in use in the Dehra Dún,

Dehra Dún lime kiln.

FIG. 13.

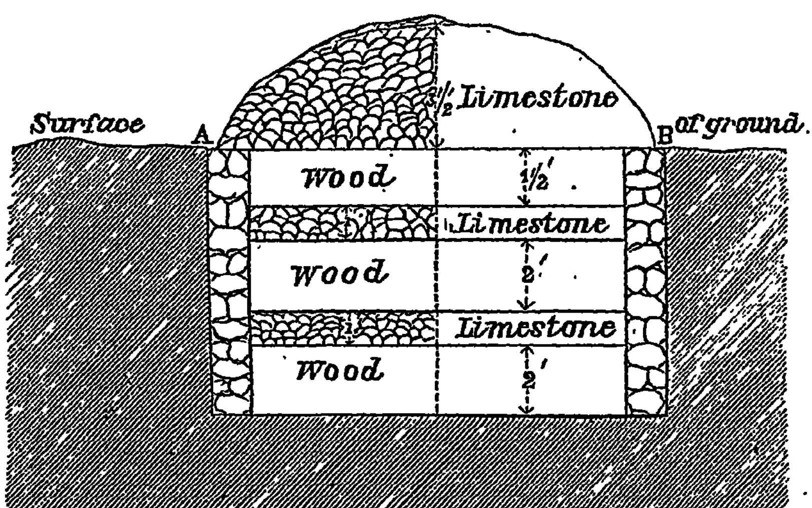


Figure 13 shows a section through the kiln charged with limestone and wood ready to be fired.

FIG. 14.

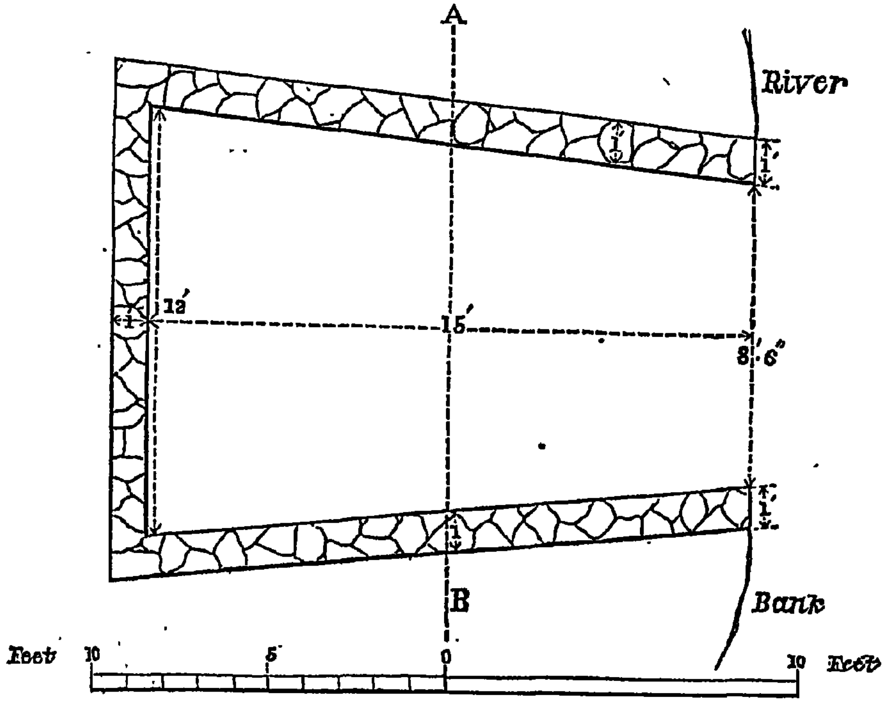


Figure 14 shows the plan of an empty lime kiln. The walls are usually made of boulders set in mud mortar. The base of the kiln slopes inwards.

In that District, limestone boulders are collected from the dry beds of streams and lime is burnt on the banks of the streams in which the boulders are found. A pit is first dug in the bank of the required size and is so placed that such currents of air as exist are utilized in forming a draught to help the wood to burn rapidly. The base of the pit is horizontal where the banks are high; but where the banks are low, the base usually slopes downwards from the front to the back of the kiln. The back of the pit is generally made wider than the front. The back and sides of the pit are made vertical, lined with stone and often plastered with mud. Alternate layers of wood and stone are placed in the pit until the general level of the surrounding ground is reached, and a dome-shaped heap

of limestone boulders is then placed on the top. The kiln is lit by placing brushwood against its outer face and setting fire to it. The time taken for the kiln to burn varies with its size, a kiln such as is shown in figures 13 and 14 takes about a week to burn through. If the kiln is burning too quickly, more limestone can be added to the heap of boulders at the top, and if it is burning too slowly some of the boulders can be taken away from this heap. There is no other means of regulating the rate of burning. There is a considerable waste in this method, and the quality of the lime produced is variable, while a large proportion of the stone is always very much under-burnt. The under-burnt stones are placed on one side and put into the lowest layer of a fresh kiln to ensure their complete calcination the next time.

The lime produced from the Dún kilns is divided into three classes as it is taken from the kilns. The first class is pure, properly burnt, white lime, free from all lumps and impurities, and is sold in the station of Dehra for R40 per 100 maunds at the kilns; the second class lime is dirty in colour and contains a proportion of under-burnt stones, it is the result of the less pure portions of the limestone burnt and fetches R25 per 100 maunds. The third class lime includes all the refuse lime of the kilns and contains a good deal of improperly burnt stone and foreign matter and is generally sold mixed with the second class lime. The prices of lime in the district are lower than those given above.

§ 26. CONTINUOUS KILNS.—The shape and size of continuous kilns vary very much with the quantity of lime required. The volume of wood required to burn a given volume of lime is very much less than in the case of intermittent kilns, the quality of the resulting lime is better and more uniform than that obtained from an intermittent kiln, while the volume of under-burnt stone is very small. Figures 15 and 16 show the construction of a continuous kiln built by Mr. Philip Mackinnon at Mussoorie. Mr. Mackinnon has found that 642 cubic feet of limestone from a massive deposit, and 410 maunds of green

water, and will not set hard unless exposed to the action of the air.

(2). *Slightly hydraulic lime.*—This results from limestone containing an aggregate of 10 per cent. of impurities, the most important of which is clay. Such a lime sets to the consistency of soap after total immersion in water for twenty days.

(3). *Hydraulic lime* is obtained from limestone or other calcareous substances containing from 12 to 20 per cent. of substances other than calcium carbonate. A hydraulic lime sets hard in six or eight days when immersed in water.

Kankar yields hydraulic limes, some of which are slightly, others eminently, hydraulic.

§ 28. STORAGE OF LIME.—Stone lime which is to be used in building construction should be slaked shortly before it is actually used. Consequently the quicklime which is obtained from the kilns must be stored in covered sheds, thoroughly protected from the rain, and kept as dry as possible. If exposed to rain the quicklime will become slaked and will lose its power of setting. Even in sheds the outer portions of stone lime deteriorate by exposure to the moist atmosphere.

When lime is bought from contractors, care must be taken to see that they do not mix any old surplus lime, which is partly, if not altogether slaked, with the freshly made lime they offer you, as this is very commonly done by them if they are not carefully looked after.

§ 29. THE USE OF LIME.—Lime enters into the composition of the following materials which are all in common use in the construction of buildings :—

(1) mortar,	(4) plaster,
(2) cement,	(5) whitewash,
(3) concrete,	(6) distemper.

Pure or fat limes are only suitable for application in thin layers to external surfaces, exposed to the action of air; for, in order to set, they must combine with carbon dioxide and give up the greater part of the water which they contain; and if they are kept moist and free from carbon dioxide they will remain

soft for an indefinite period. This class of lime is consequently unfit for use in the interior of thick walls, in the foundations of buildings or under water. Pure limes dissolve freely in rain water, and in consequence must be protected from the weather.

Hydraulic limes are suitable for the construction of thick walls, for ordinary building purposes, where they are not exposed immediately to the direct action of water, or where that action is not severe. There is less danger of unskilled workmen spoiling good work when using fairly hydraulic limes than when using eminently hydraulic limes or cements, as the former take a longer time to set. The power which hydraulic limes have of setting under water or in the absence of air is due to the clay which they contain. This quantity varies from 8 to 30 per cent.

§ 30. COMPOSITION OF MORTAR.—Mortar consists of slaked stone lime and sand, or pure kankar lime mixed with water and brought to a pasty state. If cement is used instead of lime the mixture is called cement mortar. A cement mortar sets more quickly and is much stronger than ordinary lime mortar.

Mortar is used in building construction to bind together the bricks or stones of which the walls are composed.

Mortar is applied while in a pasty state and thus affords a good bed for the stones or bricks to lie on: it prevents the inequalities of the stones from bearing one on another, and helps to distribute the pressure equally. The quality of mortar depends upon that of the materials used in its composition, the proportion of these materials and the way in which they are mixed. Hydraulic limes should be used for ordinary building purposes, but where extra strength is required cement may be used instead. Mortar should be ground wet.

The *water* used should be free from mud, clay, and other impurities. Salt water should not be used.

The *lime* used should be in a state of powder, it should be free from ashes and lumps of all kinds, and, if made from stone, must have been freshly slaked. The lime to be slaked should

be placed in a heap and one-third to one-half of its volume of water should be added. The water and lime are then thoroughly mixed together and the resulting slaked lime is left until the next day when the process of slaking will be complete. The lime is then mixed with sand as required to form mortar. The time required for slaking lime depends upon its hydraulicity, the more hydraulic a lime is the more difficult is it to slake and the longer will be the time required for the process. Fat limes will slake in a few hours; but hydraulic limes require from twelve to forty-eight hours to slake, after water has been added to them, before they are ready for use. Lime sufficient for two or three days' work only should be slaked at one time. A pure lime requires more water than a hydraulic one; a lime which has been recently burnt requires more water than one which has been burnt some little while.

The *sand* used in making mortar may be obtained from pits, river beds, the seashore, or by reducing soft sandstone to a state of powder. It should be perfectly clean, and free from clay and other impurities which would prevent the lime from adhering to it, and its grains should be sharp and angular. The size of the individual grains does not, as a rule, affect the strength of the mortar. If very fine joints are required, a fine-grained sand must be used, otherwise the coarser-grained varieties are preferable, in that they render the mortar more porous and consequently better able to set. Calcareous sands are better than siliceous ones. The salt present in sea sand attracts moisture and causes dampness so that such sand, unless well washed, should not be used in the construction of houses. All organic matter should also be carefully separated. *Pit sand* is angular, porous and has a rough surface; it however often contains clay and other impurities, but if it can be obtained pure, is the best sand procurable. *River sand* is not so angular or sharp as pit sand, it is generally freer from clay and other impurities, and, as it is usually white and fine, it is suitable for plastering. *Sea sand* is wanting in angularity, attracts moisture, and should consequently be care-

fully washed before being mixed with lime for ordinary building purposes. For hydraulic works it is as good as any other.

Preparation of sand.—The sand should be passed through a screen or sieve in order to separate it from lumps and stones. If considerable quantities of clay or loam are mixed with the sand, it should be washed. This may be done by stirring it in a trough full of water, through which a stream of water is allowed to run so that the clay and other fine matter is carried away and the sand is left behind.

Tests for a good sand.—A clean sand leaves no stain when rubbed between moistened hands, the size and angularity of the grains can be judged by the eye or touch, while the presence of salt can be detected by the taste.

Substitutes for sand.—When sand cannot be obtained *burnt clay* may be used instead. The clay may be burnt in a bonfire of coal or wood, layers of fuel and clay being placed alternately and the whole mass set fire to. Only thoroughly burnt pieces of clay should be used, as half-burnt pieces would injure the mortar. In India, *Surkhi*, *i.e.*, powdered brick, is often used as a substitute for sand. It should only be made out of properly burnt bricks. These two substitutes must not be used with lime made from kankar as it already contains a good deal of clay in its composition and no more should be added. Crushed cinders from a coal fire or the chips from dressed stone ground to a powder may sometimes form good and economical substitutes for sand.

§ 31. PROPORTION OF INGREDIENTS.—The addition of sand does not increase the strength (*i. e.*, the cementing power) of the mortar. Sand is added chiefly for the sake of economy. The addition of sand increases the resistance of mortar to crushing, as well as its porosity and cohesion, but if in excess weakens its tensile resistance. The presence of sand facilitates the process of setting, and lessens the shrinkage of mortar when drying and so prevents it from cracking. The strength of the mortar should, if practicable, be equal to that of the building material used.

In Upper India, the usual proportions of sand and shaked lime in mortar are—

1 of stone lime to 2 of sand (by volume): or
1 of stone lime to 1 of sand and of surkhi (by volume).[1]

If kankar lime is used, surkhi must not be added. Coarse sugar is often added to the water used for making mortar, when pure lime only is available, in the proportion of 1 lb of sugar to 8 gallons of water. Sugar must not be added to mortar made with kankar lime.

The beneficial action of sugar[1] is due to the greatly increased solubility of lime in a saccharine solution. Whilst water dissolves only 1 per cent. of lime, a moderately strong solution of sugar will dissolve as much as 3 per cent.; it is evident that the dessication of the sugar solution will tend to strengthen the mortar by allowing the lime to crystallize, besides placing it in a more favourable position for combination with the sand. Ulteriorly, the sugar becomes converted into carbonic acid and water, another circumstance tending to strengthen the interior of the mortar.

§ 32. MIXING THE MORTAR.—Mortar for small works is usually mixed in shallow pits dug in the earth, which may be lined with brick. The ingredients of which mortar is composed should be thoroughly mixed in a wet state, and theoretically no two grains of sand should remain together without an intervening film of lime. In hot weather, care must be taken to prevent the mortar from drying too quickly.

When a considerable quantity of mortar is required a mortar mill may be found economical. The mortar mill in common use in India is constructed as follows: a circular trough is first prepared in the ground of any convenient radius and lined with burnt bricks; a post is firmly driven into the ground at the centre of the circle from which the sides of the trough were laid out. A beam which rotates about a pin driven into the post is furnished with a stone wheel which revolves on its edge and rotates in the trough. The wheel is made to rotate in the trough by a pair of bullocks. The ingredients of the mortar are then placed in the trough and the required amount of water

[1] Civil Engineering College papers (Madras), No. X, Part I, page 31, 2nd Edition, 1877.

added. They are thoroughly and intimately mixed by the revolution of the wheel in the trough.

§ 33. APPLICATION OF MORTAR.—In applying mortar it is important to thoroughly wet the materials which are to be joined, for if the moisture which enters into the composition of a hydraulic mortar is suddenly withdrawn it will not harden. Dry bricks and porous stone absorb a large amount of water; so that if mortar be applied to the dry surfaces of such materials, the moisture which it contains will be sucked out and the mortar will crumble, whereas if the surfaces have been previously wetted so that they cannot absorb any more water, the mortar will be able to set. Bricks or porous stone, such as sandstone, ought to be steeped in water for at least two hours before use, though, for a compact stone, such as granite, it is sufficient to wet the surface at the time of laying. The mortar should be mixed as stiff as it can be used without inconvenience, and without incurring the danger of the joints remaining incompletely filled when the stones or bricks are laid. The mortar should be prevented from drying rapidly after it has been applied. For this purpose, the walls ought to be kept continuously wet as they are being built, and when work is left off for the night an edging of mortar should be made round the top course, say 1½ inch high, and water poured into the trough thus made. Where new and old work have to be joined, the old work should be well saturated with water for two days previously and the two portions of the wall properly bonded together. It is rare to find the above rules adhered to by ordinary masons.

After a time the mortar used *sets*, that is, hardens. The process of hardening continues until the mortar has taken up as much carbon dioxide as it is capable of re-absorbing. The process of hardening is more rapid at first than afterwards, and consequently more water is required at this time. Hence it is customary to keep the walls wet in order to ensure the mortar setting properly, though in reality they do not dry completely for a long time.

Freshly-made mortar is liable to damage from frost, and should be protected from it by a layer of grass, or some other covering. When freezing, water has a strong tendency to become clear of impurities, so that ice formed from it does not contain particles of mortar. Collecting in crevices, the water becomes ice, and in expanding causes the mortar to disintegrate, while the mortar being deprived of water does not set in a homogeneous mass.

§ 34. CEMENT.—Cements are found in nature, and may also be made artificially. Cements consist of a mixture of lime and very finely powdered clay; the constituent parts being intricately mixed. They differ from lime, in that they do not slake and in that they set very much more quickly and become much harder. The best known artificial cement is Portland cement, and it contains from 72 to 77 per cent. of lime and from 28 to 23 per cent. of clay.

Mortars made with cement are very much stronger and set very much more quickly than those made with lime. Cements are very much more expensive than lime and are consequently used only where great strength or rapidity of setting is necessary.

§ 35. CONCRETE is an artificial compound formed by mixing lime or cement mortar, with some hard material such as broken stone, gravel, pieces of broken brick or burnt clay. These ingredients are thoroughly mixed together so as to form a conglomerate. The strength of concrete depends chiefly upon that of the mortar used.

It is used chiefly in strengthening the foundations of buildings and in making floors and roofs. It is also used in making blocks of artificial stone, and sometimes for arches if more economical than masonry.

The ingredients used to make the mortar should be proportioned so as to make the strongest mortar possible with the materials available. The *aggregate*, as the broken stone is technically called, may be of any hard substance, that can be easily and cheaply broken up into small pieces. If porous mate-

rials, such as broken brick or limestone, are used, they must be well wetted before they are mixed with the mortar. If a hard substance, such as quartzite, is used, this precaution is not so necessary. Angular fragments of stone are the best, as they, in themselves, help to bind the mass together. The size of the stone should be as uniform as possible, and may vary from ½ inch to 2 inches in diameter according to circumstances.

The volume of mortar to be added to any given quantity of stone may be determined as follows. Fill a wooden box with the fragments of stone (previously moistened), consolidate them thoroughly and fill the box with water. The volume of the water added will give the volume of the spaces left between the stones which must be filled with mortar. If the aggregate is stronger than the mortar, the smaller the volume of mortar added the better. For ordinary work the following proportions may be used :—

$$\left.\begin{array}{l}\text{1 part of quick-lime,}\\ \text{2 parts of sand,}\\ \text{5 to 6 parts of aggregate,}\end{array}\right\}\text{by volume.}$$

A little more mortar than will exactly fill up the empty spaces between the stones should be added so as to make the top surface smooth and even.

If a very strong concrete is required cement may be substituted for lime, and in this case one part of cement should be added to ten parts of sand.

§ 36. METHOD OF MIXING CONCRETE.—The materials of which concrete is made may all be worked together in a dry state and water gradually added until the component materials are intricately mixed. Care should be taken that too much water is not added, as an excess of water would carry away some of the lime and finer materials with it. Or the mortar may be first mixed and then added to the broken stone or brick which should have been previously moistened. The first method is the one most generally adopted as it is the least expensive of the two.

§ 37. METHOD OF LAYING.—Concrete should be laid in courses of from 3 to 6 inches according to the nature of the work. Each course should be well rammed and consolidated before the next is added. The ramming should be continued until the concrete has partially set, *i. e.*, until a stick dropped on it from a height will rebound. Each layer should be allowed to set completely before the next course is added. When a fresh layer of concrete is to be added, the surface of the concrete already laid should be carefully swept, wetted and (if the work is old), roughened with a pick; after this has been done the fresh layer of concrete should be added and rammed as before. A little extra mortar should be added to the top layer of concrete; this will work through and give it a smooth flat surface. If thick blocks of concrete are being made they should be constructed in layers, each layer being well rammed before the next is added, the upper surface of the block should be covered with sand and watered for several days in order to ensure the block drying uniformly throughout, and that the outer portions do not dry while the mortar in the interior is still in a pasty condition. When concrete is put down for a floor or in foundations of a structure it should be evenly spread and not thrown from a height, for if this be done, the heavier particles, in the act of falling, will become separated from the mixture.

§ 38. PLASTER is a substance which is put on to the outside of buildings in order to keep the moisture from entering the walls and also to give them a smooth and neat-looking surface. Plaster is also placed on internal walls to make their surfaces smooth preparatory to being whitewashed, distempered or painted.

In India, the composition of plaster differs from that of ordinary mortar only in that it contains a larger proportion of sand or surkhi. The additional sand prevents the plaster from cracking while drying. The lime used should be very carefully slaked. Plaster is usually applied with a trowel and consolidated by being patted with a small wooden mallet.

If the plaster is applied in two or more layers, the first layer

should be scored across with the trowel to allow the second coat to adhere firmly to it: hemp, chopped straw or hair, should be added to the first layer of plaster in order to make it adhere properly to the wall.

The last layer of plaster is smoothened with a board: the surface may be made still smoother by the addition of a mixture of very fine lime and sand. In Madras the last layer of fine lime and sand is ground by hand between two stones, applied in a thin layer and smoothed off with a polished pebble.

The surface to be plastered should be well cleaned, but the mortar joints should be left rough in order to give a better hold to the plaster.

Fresh water and fresh water sand must be used in making plaster, for if salt water is used the walls will be permanently damp.

§ 39. WHITEWASH is a thin solution of slaked lime, to which some ingredient, such as gum, *size*, or rice water is added in order to make it adhere to the wall or other surface to which it is applied. Where *size* or rice water are used they are added to the slaked lime; when gum is used it is dissolved in a small quantity of water and added to the solution of lime.

One-and-a-half seers of stone lime and ·05 chittaks[1] of gum mixed with water until its consistency is such that it will not immediately drop from a brush dipped into it, will be sufficient for 100 square feet of wall surface. *Size* is made by melting 1 lb of good glue in a gallon of hot water.

Whitewash made from fresh lime adheres better than that made from old lime.

If common salt (sodium chloride) be added to the lime in the proportion of 1 of the former to 3 of the latter,[2] by weight, a hard surface which cannot be removed by scrubbing, and is said to withstand a heavy downpour of rain, will be obtained.

The surface to be whitewashed should be well cleaned and smoothened before the solution is applied. If an old wall is to

[1] 1 chittak = 2 1/16 ounces, *avr.*
[2] Indian Engineering, 3rd November 1874.

be whitewashed, the former coat of whitewash should be scraped off before the new coat is applied. Whitewash should be applied with a soft brush or bundle of rags. If more than one coat is applied, the first must be allowed to dry before the second coat is added.

Whitewash forms a cheap and clean covering to a wall, and is to be recommended on sanitary grounds. It does not adhere easily to a smooth or non-porous surface.

§ 40. DISTEMPER.—Whitewashed or plastered walls may be tinted by applying colouring matter dissolved in water to which *size* has been added; this mixture is called *distemper*. If the colour is too dark a little slaked lime may be added.

Whiting (powdered chalk) and colouring matters form the base of distemper. One quart of *size* in the consistency of weak jelly should be added to 6℔ of whiting, and the colouring matter which is to be used and the mixture strained. The mixture is diluted with water before use until it has the same consistency as whitewash.

In India, the colouring matter is commonly added directly to the last coat of whitewash which is applied to the wall. The colouring matters most commonly used[1] in Northern India are red and yellow ochre; indigo, sulphate of copper (*Nila-tutya*) for blue colours; a red earth called (*Hirmči*) and orpiment (*Hartal*) for yellow shades.

SECTION VI.—TIMBER.

§ 41. NATURE OF WOOD.—The term *timber* includes all kinds of wood which are used for technical purposes. *Wood* is the substance which forms the principal part of the roots, trunk, and branches of trees and shrubs.

Woods differ in strength, hardness, durability, appearance and weight, and consequently in their fitness for the various purposes for which they may be required.

[1] Roorkee Treatise of Civil Engineering in India, Vol. I, page 214 (3rd Edition, 1878).

If the stem of a tree is cut across, we shall see, in many cases, a number of concentric layers or rings; in some species these are very distinct, in others they are almost, if not entirely, absent. As a rule, each layer represents the growth of one year, but this is not always certain. The thickness of the different layers vary owing to differences in the amount of nourishment received, the climate of each year, and the prevailing winds. The thickness of the same layer at different parts of the stem also varies; the thickness of these layers depend upon the rate of growth of the tree. The innermost part of the stem of the tree is called the *pith*, and in mature timber-producing trees occupies a very small proportion of the stem. The portion of the stem which surrounds the pith is the hardest and most durable portion and is known as the *heartwood;* it consists of dead cells, *i.e.*, cells which have thickened walls, which contain no food materials and which have ceased to take an active part in the increase in size of the tree. The outer portion of the stem consists of still living cells, and is called *sapwood;* it is covered in its turn by the *bark*. This term includes all the tissues which form the external protective covering of the stem of the tree. The *sapwood* is usually lighter in colour and softer than the heartwood; it is not so durable, and is especially liable, owing to the food material contained in its cells, to be attacked by the larvæ of insects as well as the spores of fungi.

Strands of cellular tissue extend, in some trees, from the pith or heartwood outwards towards the bark; these strands constitute the *medullary rays* of the botanist, and the *silver grain* of the carpenter. The breadth and height of medullary rays is very small as compared with their length; the height is usually greater than the width. Some of them extend from the centre of the tree to the circumference, others begin in the heartwood, and extend for varying distances towards the bark.

The proportion of the heartwood to the sapwood varies much with the age and species of the tree, and also with the locality in the same species. A young tree will have proportionately more sapwood than an old and mature one of the same species. The proportion of the sapwood also depends upon the situa-

tion of the tree, its rate of growth, and the nature of the soil. Mature trees, *i.e.*, trees which have nearly completed their growth in height and have fully developed vigorous crowns, will produce timber of the best quality. Over-mature or under-mature trees do not yield timber of such good quality as that obtained from mature trees. The timber obtained from a tree which has formed annual zones of nearly equal breadth is better for most purposes than that obtained from one which has grown at varying rates during successive years. In the case of conifers, however, trees with narrow rings yield better timber than those with broad rings, since the wood produced in the autumn is stronger than that produced in the spring.

§ 42. SEASON OF FELLING.—The season of the year at which trees are felled is sometimes of considerable importance in so much as it affects in a marked degree the durability and seasoning properties of timber cut from the same species of tree, quite independently of its durability as compared with timber derived from another species. Practically, trees must be felled when labour can be obtained; and only when labour is to be obtained at most seasons of the year is there any choice in the season of felling.

From a physiological point of view the best time of the year for felling trees, so far as the durability of the resulting timber is concerned, is that at which the stem of the tree contains the least quantity of water and food materials; provided that the state of the atmosphere is favourable to the slow and uniform evaporation of the water which exists in the stem of the tree when felled.

As far as trees which have a distinct heart-wood are concerned, the quantity of food materials in the stem is not of much importance since they are contained chiefly in the sapwood and this part of the tree should not be used for timber. The stem probably contains the least volume of food materials just *after* the first flush of leaves, at the beginning of the period of active growth in the spring, as at that time the greater portion of the food materials stored in the stem

will have been used up in the processes of growth in length and will not have been replaced through the activity of the leaves. In the case of trees which flower gregariously such as Sâl (*Shorea robusta*), the stem will contain the least quantity of food materials after a complete seeding and before the new leaves are fully developed.

The quantity of water in the stem is greatest just before the tree enters into the most active period of vegetative growth annually; and least just about the period of its partial (in evergreen) or total defoliation (in the case of deciduous trees): while the quantity of water in the stem is small during that period of the year at which no active growth in length, or elaboration of food materials, takes place, *i.e.*, when the tree is *at rest*.

A certain amount of heat, light and moisture are necessary for the processes of growth. When these are present in the most suitable quantities, the growth of the tree is at its greatest, and as one or all of these conditions become less and less favourable so does the growth become smaller and smaller until a time is reached when no actual growth takes place and the tree simply exists, the quantity of water taken in by the roots being only just sufficient to replace that evaporated from the leaf surfaces. Consequently, when the tree is *at rest* the leaves are passive (*i.e.*, not actively engaged in assimilating food materials) and the quantity of moisture, containing salts in solution, taken up by the roots, will be less than when the tree is growing actively and the total quantity of moisture in the stem of the tree will also be less. The fall in temperature in autumn in Europe, or at the end of the rains in India, is probably the chief cause which practically determines the time at which growth is no longer possible and the season of rest begins.

This shows that the period of rest of a tree is a favourable season for felling trees cut for the production of timber.

The power of seasoning well (*i.e.*, giving off a large propor-

tion of the water contained in the wood at the time that the tree is felled without the development of serious cracks and splits and without *unequal* change of form (*warping*), is a most important one; and is very considerably affected by the season at which the trees are felled. If the tree is felled at a season of the year when the evaporation of the water can take place slowly and uniformly, the timber must necessarily season better than if felled at a period when rapid and unequal drying must necessarily result.

So far as the plains of India are concerned, timber will dry more slowly and uniformly during the cold weather season than at any other season of the year at which tree felling is practicable. The trees should be felled as soon after the end of the rains as possible, provided growth has entirely ceased, so that the timber may have parted with the greater part of its moisture before the temperature rises and the cold weather passes into the hot weather.

In the spring, *i.e.*, the end of the cold weather, the stems of the trees may actually contain the smallest absolute volume of water, but the conditions of the atmosphere are very unfavourable for the slow and even evaporation of water which is necessary for the seasoning of the wood: whereas, unless all the timber is extracted from the forests before the rains, it will be very seriously injured by insects and fungi during that season of the year.

In the cold weather season in the plains of India, trees probably contain the greatest amount of reserve materials stored up in their tissue, for use when the next period of active growth sets in. But as these food materials are stored in the sapwood and to a slight extent in the medullary rays, their presence should not materially affect the quality of the heartwood of the tree; and so far as this is concerned, the period of the year at which it contains the least moisture, provided the atmospheric conditions are favourable to good seasoning, should be the best for felling timber-producing trees. The upper hill

forests of the Himalaya do not fall into the same category as the plains or submontane forests and must be considered separately. The climate of these forests approaches more nearly that of Europe, and experience gained in Europe may be fairly applied with certain modifications to that of this class of Indian Forests.

The same broad principle may be said to hold good, namely, that the trees should be cut when they are at rest, provided the atmospheric conditions are favourable to the slow and uniform evaporation of water from them. The European principle of summer felling cannot be universally applied to them since the season of growth is followed by the rainy season, and in localities where the rainfall is heavy, systematic tree felling is not always then practicable.

In the Upper Darjeeling hill forests, where the rainfall is exceedingly heavy and continuous, trees are felled only during the winter months, and all work in the forests practically stops with the commencement of the rains. The snowfall in these forests is too light to interfere with the work. The trees exploited nearly all belong to the broad-leaved species.

In the North-West Himalaya where the upper hill forests consist principally of the Deodar (*Cedrus Deodara*) and other conifers, trees are felled during the rains and on into the cold weather until work is stopped by the fall of snow. The chief period of growth of pines and firs in this locality is April, May and June. The trees are felled all the year round except the months of December to February. This is to some extent necessitated by the fact that labour has to be imported and trees must be removed when labour can be obtained, rather than at the theoretically most favourable period of the year.

The views of Professor Nanquette on the best season for felling timber trees[1] in Europe may be epitomised as follows. The old opinion was that the best time for felling timber trees was the end of autumn and winter. It was stated that wood,

[1] Exploitation, débit, et estimation des bois, par H. Nanquette. Nancy, 2nd Ed., 1868.

cut during the period of rest of the tree, lasted longer when used as timber, and as firewood burnt more easily and at the same time gave out more heat, than if felled when the tree was growing actively.

Conifers have been exploited from time immemorial in the Vosges mountains in the summer, and the quality of the timber does not seem to have been affected by it.

Many enlightened practical men, in agreement with the teachings of physiology, agree that, if barked as soon as felled, the wood dries more easily and more completely, that it is less liable to warp, is superior as regards whiteness and lustre, and is lighter and more easily transported. This result of experience tends to shake the accredited opinion, as regards broad-leaved species, and seems to be in favour of exploiting trees in summer after the sap has risen, if not in what concerns their calorific properties, at least from the point of view of their durability. However, it would be imprudent to decide definitely at present and until numerous experiments precise and comparable have decided the question definitely, it seems proper to follow the old practice. It is probable, moreover, that the season of felling only influences those woods which remain more or less completely in a state of sapwood throughout their existence, or on the sapwood of trees which have a well-defined heart-wood.

After a tree has been felled, its timber shrinks more or less rapidly according to its structure, the season in which it has been cut, and the state of the atmosphere of the place in which it was. This contraction of the tissues due to the evaporation of a part of the sap contained in the wood causes splits which may be large enough to alter the solidity of the wood and render it unfit for certain uses.

It is necessary that drying should take place slowly in order to avoid large cracks, and should commence as soon as possible after the wood is felled in order to preserve the wood from the effects of fermentation.

The felling of trees in winter fulfils these conditions pretty

well, because fermentation is less active, the drying takes place gradually, and the tree will reach summer sufficiently dry not to be hurt by the heat of that season.

If broad-leaved species are felled in the summer, the bark should be taken off as soon as the tree is felled, and the trees should be placed as far as possible in a dry and shady place. These precautions are especially necessary in hot countries. They are always easy to take in coupes, and large pieces difficult to move can be protected from the heat of the sun by covering them with some of the rubbish made in exploiting the trees.

§ 43. Where the bark is of intrinsic value and has to be removed intact, the tree must be felled when the sap is rising, *i.e.*, just before the period of growth in length takes place, as at this period the bark separates more readily from the stem.

In Burma, Teak (*Tectona grandis*) trees are *girdled* from two to three years before they are felled. This process consists in removing the bark and the sapwood for a width of from 4 to 6 inches all round the trunk of the tree so as to completely expose the heartwood the whole way round the stem. The lower edge of the incision should slope upwards, the upper edge downwards. The flow of sap from the roots to the crown of the tree is thus intercepted and the tree dies, but if even small shreds of sapwood be left covering the heart-wood the tree will not succumb.

In the case of trees with no definite heart-wood, the girdle, even if made of considerable breadth, may fail to make sufficient disturbance in the organization of the tree as to cause death (*e.g.*, *Terminalia Chebula* and *belerica* and most species of *Ficus*). In Jaunsar, experience has shown that if only the bark is removed in the spring when the sap is rising, the trees ultimately die in nearly every case where the bark has been entirely removed. Firs and pines die in the second or third year after girdling: oaks live as long as five or six years after this operation. Trees should be girdled, if possible, in the cold weather, before the period of growth begins; when growth

begins, the nutritive materials and moisture in the stem of the tree will be drawn up into the young shoots and leaves, and will be used up in the processes of growth. Growth will continue so long as the leaves receive a sufficient supply of moisture; this supply is drawn from the soil by the roots, and passes up the stem through the sapwood, the cambium layer and the living portion of the bark. The process of girdling completely or partially intercepts this source of supply, and the tree in consequence withers and dies.

One of the leading timber contractors of Burma states that teak which has been girdled during the rains, seasons more thoroughly than if girdled at any other time of the year, and that such timber floats better. This may be probably due to the bark rotting off during the first rains instead of adhering closely to the sapwood as it does when girdling is done at a time of the year when the foliage rapidly dries. (*Dr. J. Nisbet.*)

§ 44. SEASONING TIMBER.—Tredgold[1] defines *seasoned* timber as timber which has lost one-fifth of its weight when green, *i. e.*, freshly cut[2]; and *dry* timber as wood which has lost one-third of its green weight. Seasoned timber may be used in ordinary building construction; but only dry timber should be used by joiners, cabinet-makers, and others.

The object of seasoning timber is to expel the water and sap (*i.e.*, water containing organic food-materials) which remain in the tree after it has been felled, as the presence of these food materials containing proteid and albuminous substances induces decay.

Wood that has been properly *seasoned* is much more durable than that which is unseasoned: it is far less liable to the attacks of white ants and other insects, and will not contract, expand, warp, or be materially altered by changes in the atmosphere, so that for all parts of a construction where close fitting is required (*e. g.*, doors and windows) dry or at any rate well seasoned wood should be used.

Timber is said to season well when it dries uniformly, and

1 Tredgold's Carpentry by Hurst, 4th Edition, page 343.
2 This does not apply to trees which are girdled for two or three years previous to being felled.

neither cracks nor splits, and when cut up into thin pieces neither splits nor warps. A well-seasoned piece of wood should not be materially affected by very wet or very dry weather, provided its outer surface is protected.

The chief methods of seasoning wood are—

(1) natural seasoning,
(2) water seasoning,
(3) artificial seasoning—
  (*a*) by boiling and steaming,
  (*b*) by smoke drying,
  (*c*) by extraction of sap,
  (*d*) by hot air.

In forest works in India artificial seasoning is, as a rule, impracticable, so these methods will not be described in detail. The first method is the one most generally adopted, though in the case of timber that is floated for considerable distances, the prolonged immersion in water undoubtedly materially helps the process of seasoning.

§ 45. NATURAL SEASONING.—Natural seasoning is the most certain way of rendering timber durable. In this process of seasoning, as the name implies, the wood is allowed to season without the assistance of any artificial means to drive off the moisture which it contains.

The process consists of allowing the logs to dry naturally and only assisting the process of drying by natural means, such as barking the logs, cutting them up into planks, scantlings or large beams, and arranging for as thorough a circulation of air as the circumstances of the case will permit.

When a tree is felled it should, (if it has not been previously girdled and allowed to season standing, as is the custom in Burma) if practicable, be barked and left in the forest for several months to season, and after that period has elapsed it may be cut up into logs, scantlings or planks, and these in their turn submitted to a further period of seasoning.

The removal of the bark has the double object of preventing insects from laying their eggs under it; and also of allowing the process of drying to go on unchecked in every direction. The practice of girdling the trees and allowing them to season standing lessens considerably the danger from attacks of insects while the tree is seasoning in the log, and also the chance of the timber being destroyed by forest fires—sometimes a very important consideration in India.

If the tree is felled, the log should be left in a dry, shady situation, and should be placed in such a position that air can circulate freely around it.

The process of natural seasoning should be gradual, so as to ensure slow and regular drying, as irregular and rapid drying causes the timber to split. If it is impossible to avoid exposure to the sun, the log should be covered with a thin layer of earth in order to lessen its drying effect on the log. Trees may be allowed to season as a whole, or, if large, may be first partially or wholly converted.

Some species of trees season very much more uniformly and quickly than others. Teak (*Tectona grandis*), mango (*Mangifera indica*), and toon (*Cedrela Toona*) season well, while sâl (*Shorea robusta*) may be taken as an example of a wood which seasons very slowly and unequally, and is long liable to warp and split.

Where considerable quantities of seasoned timber are required regularly, special steps should be taken to ensure their seasoning properly. An open shed should be constructed, so that the timber may be protected from the sun and rain and sheltered from scorching winds. If there is no danger of rain being driven into the shed, no side walls are necessary, as the more freely the air can circulate the quicker and more evenly will the timber season. If the rain beats in, in one or two directions, wooden walls should be erected on those sides only.

The floor of the drying shed should be slightly raised and

well drained. The beams, planks and scantlings should be stacked in such a way that the air can circulate freely and as equally as possible round them. The timber should be kept from contact with the ground.

Short small blocks of wood should be put between the layers of scantlings and planks, if stacked horizontally, in order to ensure a thorough circulation of air.

Equal drying is promoted by turning the pieces of wood over frequently (where practicable) and keeping them free from damp; evaporation takes place more rapidly from the ends than from the sides of a piece of wood, and from the upper than from the lower surface. The turning of the pieces of timber is of much greater importance at the commencement of the process of seasoning than later on.

In the saw mills in Burma, the stacks of Pyinkado (*Xylia dolabriformis*) sleepers are covered with saw-dust to prevent the wood cracking, while the ends are smeared with thick crude earth-oil, or plastered with a quarter of an inch of cowdung to prevent such excessive evaporation as would cause cracks to develop. (*Dr. J. Nisbet.*)

Planks, scantlings, and poles dry more rapidly if stacked in an upright position; but to do this a greater amount of space is required.

The following table taken from Tredgold's Carpentry gives the time required by scantlings to season in Europe relatively to their dimensions:—

Length in feet.	Breadth in inches	Thickness in inches.	Time required for seasoning in months.	Time required for drying in months.
10	6	6	6½	29
10	8	8	8½	39
12	10	10	10	48
12	12	12	12	57
12	14	14	14	66
12	16	16	17	76
18	18	18	19	86
20	20	20	21	96

Under cover five-sevenths of the times given above will be sufficient. No similar table is available for India.

The times given in this table agree with those given by Mr. Laslett[1] for oak. He states that firs only require half the time that oak does to become properly seasoned.

§ 46. WATER SEASONING.—Various methods have been introduced with a view to shorten the time required by the natural process for seasoning timber. One of the best of these is the method known as water seasoning. In this process freshly cut timber is *entirely* immersed in water for 14 days; it is then taken out and allowed to dry in an airy situation as has been described in the process of natural seasoning. Immersion in water is found to cause more rapid and more regular drying and thus to obviate warping and splitting. It also removes, to some extent, such organic food materials as are present in the sapwood. The immersion must be continuous while it lasts, as nothing is more harmful and inducive to decay than alternate immersion and drying.

Bamboos which have been seasoned through the agency of water are very much benefited by the process. They are not only rendered more durable, but are very much less liable to be attacked by the larvæ of small beetles which make channels in them in all directions and very materially weaken them. Experience has shown that in India the best way to keep the larvæ of such beetles from boring bamboos is to immerse the freshly cut bamboos in water for about 10 days. The eggs of the beetle are probably deposited on the culms of the bamboos and are washed off by the water and so got rid of.

§ 47. CONVERSION OF TIMBER.—In converting logs into scantlings or planks, the first consideration must be, as a matter of course, the dimensions and form which the timber is required to have when actually in use, and allowance must be made for any alteration in size or shape which may take place during the process of seasoning. The action of the air during

[1] Notes on Building Construction, Rivington's Series, 2nd Edition, Part III, p. 389.

seasoning by whatever process may be adopted, causes an inappreciable change in the *length* of the piece of wood, but the changes in *width* and *depth* may be considerable. Planks and scantlings should consequently be cut slightly wider and broader than they are actually required when seasoned: in practice from ¼th to ⅛th of an inch is allowed for shrinkage, squaring and planing. The shrinkage of timber seasoning in the log results in radial fissures following the lines of the medullary rays, to which the tension is always at right angles. The effect of shrinkage consequent on seasoning is shown on logs converted into quarters or planks in the following sketches, taken from "Notes on Building Construction"[1]—the Manual prepared for the Science and Art Department, South Kensington.

FIG. 17.

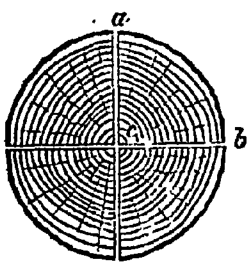


FIG. 18.

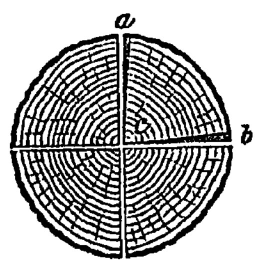
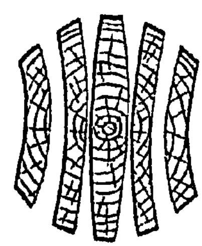


FIG. 19.



Figures 17, 18, and 19 illustrate the shrinkage of wood during the process of seasoning. Figure 17 is a cross-section of a log freshly cut into four pieces by two saw-cuts at right angles to each other. Figure 18 shows the change in form after the wood has become seasoned; the angle at c *is no longer a right angle, and the portion* ab *has contracted considerably. Figure 19 shows how planks cut out of a log change in form during the process of seasoning.*

In ordinary conversion in the forest, the object to be aimed at when cutting up a log into beams, scantlings or planks, is usually to get as many sound pieces of wood as possible, and for the saw-cuts to follow, as far as practicable,

[1] Published by Rivingtons, Waterloo Place, London.

the direction of the medullary rays, and to cut the annual rings at right angles. The shape of the planks or beams, allowing for the width of the saw-cut, should be marked on the *small* end of the log, and should be arranged in accordance with the principle above enunciated, so as to get the greatest number of sound scantlings of the required size as possible. If this be not done and the arrangement be left to chance, great waste may result. It is better to get all good sound scantlings out of a log than an actually larger number of scantlings of which some are unsound or undersized.

Beams containing the pith of the tree are considered by some Engineers to be of second quality only, and would not be used in important works.

In converting a log, we should remember that, as far as engineering works are concerned, the object to be aimed at is to get the strongest pieces of timber that can be obtained. Conversion with a view to obtain prettily marked pieces of wood belongs to the province of the carpenter and cabinet-maker, and will not be considered here in detail.

In India, the general practice is to fell the trees in the forest and to convert them on the spot. This statement does not apply to Burma, where teak is extracted in the log and converted, when required, at the large sawmills in Rangoon or Moulmein. The log is usually roughly squared with an axe before it is converted, and no special attention is, as a rule, paid to obtaining the strongest pieces of timber that it is possible to get. The pith, if any exists, is avoided, as well as such bad faults as may exist in the log. The greater portion of the sapwood is removed when the log is being roughly squared.

The strongest pieces of timber are those obtained by making the saw-cuts as nearly as possible parallel to the direction of the medullary rays and at right angles to the annual rings, because shrinkage takes place chiefly parallel to the direction of the annual rings. Referring to figure 20 it will be seen that a plank cut as shown at *a* is much weaker than one cut as at *b*. Planks cut as shown at *b* last longer, warp less, and show a much handsomer grain than if cut in the manner shown at *a*.

FIG. 20.

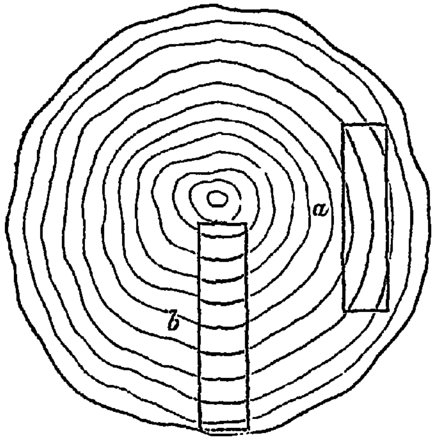


Fig. 20 represents a cross-section of log, showing at b the strongest and at a the weakest scantling (beam or plank) that can be cut out of it (after Spon).

Figures 21 and 22 show several methods of marking out planks on a log previous to conversion, in order that the saw-cuts may fulfil as closely as possible the conditions necessary to obtain greatest number of the strongest planks that it is possible to cut from the log.

FIG. 21.

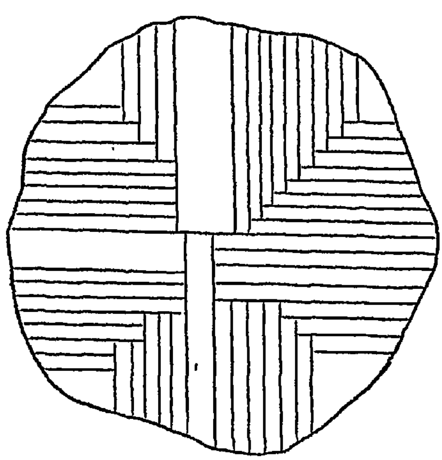


FIG. 22.

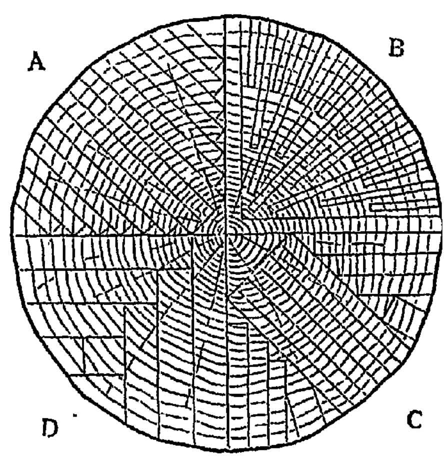


Fig. 21 shows how a log should be sawn up so as to get the greatest number of the strongest planks out of a log. The saw-cuts follow as closely as possible the direction of the medullary rays (Sciage sur maille—Nanquette).

Fig. 22 shows the different ways in which a log may be cut up, so that the saw-cuts may follow as closely as possible the direction of the medullary rays (after Spon).

The methods of cutting up logs into planks shown in figures 21 and 22 are especially adapted for the conversion of trees which have strong medullary rays (for example the oaks *Quercus* sp. sp.), as the saw-cuts pass obliquely through the medullary rays, and the planks in consequence exhibit a very beautifully marked *grain* which is especially valued for cabinet-work and other ornamental purposes. In Europe this method of conversion is applied almost entirely to oak.

The log is first cut in every case into four quarters,[1] and each quarter may be converted as shown in figures 21 and 22. The best method is shown at A in figure 22, as in this method there is no waste (in Europe), as the triangular portions form feather-edged laths for tiling and other purposes. It also cuts very obliquely across the medullary rays, and thus exhibits well the *silver grain* of the wood. The next best method is shown at B. The method shown at C is inferior to the others; that at D is most economical where thick stuff is required.

The ordinary method of cutting planks out of a log is to cut them all parallel to the same diameter, so that the planks can be placed one on the top of the other so as to re-form the log.

With regard to beams, the *strongest* beam (*i.e.* the beam which will bear the greatest weight) that can be cut out of a log is obtained by dividing the diagonal A C, see fig. 23, into three equal parts at 1 and 2, and by drawing perpendiculars from these points to meet the circumference of the circle described about A C is a diameter.

FIG. 23.

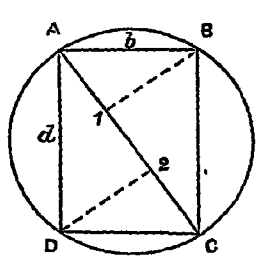


FIG. 24.

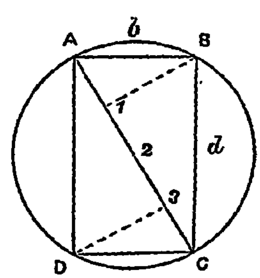


Figure 23 shows the method of cutting the strongest beam possible out of a log: b : d :: 7 : 10 nearly.

Figure 24 shows how the stiffest beam may be cut out of a log, in this case b : d :: 57 : 100 nearly.

[1] Notes on Building Construction, 2nd Edition, Part III, page 400.

The *stiffest* beam (*i.e.*, the beam which will carry the greatest weight with the least bending) is obtained by dividing the diagonal into four parts instead of three, as has been done in fig. 24, and proceeding as in the first case.

In India, beams and small scantlings are usually cut out of a log without special reference to obtaining the strongest pieces of wood. The scantlings are marked off on the small end of the log and are arranged so that the greatest number possible shall be obtained with the least possible waste. The market rate for all scantlings of the *same size* is the same, and so long as this is the case, and higher prices are not given for beams cut as shown at fig. 20 *b*, from economical reasons it would not pay to cut only such beams. Besides, if this were done the number of scantlings which could be obtained from a log would be considerably less.

§ 48. SUITABILITY OF DIFFERENT KINDS OF WOOD FOR THE VARIOUS PARTS OF A STRUCTURE.—Timber cut from different species of tree differs as regards—

(1) cohesive force,	(4) hardness,
(2) elasticity,	(5) toughness,
(3) stiffness,	(6) power of seasoning well.

(1) The *cohesive force* of a beam is measured by the force expressed as a weight, for convenience sake, that would pull it asunder in the direction of its length. This force is usually expressed in lbs.

(2) The *modulus of elasticity* or "*e*" is the weight expressed in lbs. required to extend a bar of wood an inch square in section to double its original length. This weight is the standard used when the elastic force of two substances is compared. The strains exerted on beams in buildings are resisted in virtue of this force.

(3) The *stiffness* of timber is deduced from its modulus of elasticity, and it is a comparative quality only. For example, *e* for cast-iron is 17,000,000 lbs., while the value of *e* for English oak is 1,714,500 lbs.—that is to say, cast-iron is nearly ten times as stiff as English oak.

(4) *Hardness* is the capability of not yielding to a blow or impressive force, and is proportional to *e*. Dry wood is harder than green wood, the labour required to saw the former compared to the latter being as 4 : 3.

(5) *Toughness.* That wood is toughest which combines the greatest degrees of strength and flexibility; that is, the wood which bears the greatest weight and at the same time bends most at the time of fracture.

The opposite quality to toughness is brittleness; to hardness, softness; and to stiffness, flexibility.

In Europe, oak is taken as the standard of strength, toughness, and stiffness. Each of these qualities is for convenience represented numerically by 100, and that of other woods is expressed as a percentage of this number; thus, if the toughness of a wood is represented by 75, it means that its toughness is three-quarters that of oak.

The following appearances indicate a strong and durable timber:—

(1) Equable rate of growth as shown by the annual rings being of nearly equal width and of uniform structure.

Within certain limits coniferous woods having narrow annual rings are more durable than broad-ringed stems of rapid growth. Trees (*e.g.*, like Toon, *Cedrela Toona*, grown on the banks of canals) stimulated to the production of abnormally wide annual rings, do not produce such good timber as those grown under more normal circumstances. But the mere breadth of the rings can form, *per se*, no criterion of the quality of the timber, as this depends mainly on the thoroughness of the elaboration of the sap utilized in the formation of the woody fibrous tissue. (*Dr. J. Nisbet.*)

(2) The tissues being hard and compact, the fibres on a freshly-sawn surface should be fine and shining, not woolly in appearance.

(3) In any one given species the heavier wood is always the more durable, but the specific gravity of different kinds of wood gives no true indication of their relative durability.

(4) Where woods are coloured, darkness in colour usually indicates strength, but may point to an alteration in the tissues preliminary to decay.

Beams include *rafters*, *i.e.*, scantlings for supporting the roof; *joists*, scantlings for supporting the floor; and *wall plates*, which are beams laid along the tops of walls, for the purpose of distributing the pressure supported by them equally over the whole wall. The actual size of a beam or scantling depends upon the weight it has to bear and upon its length. The depth of a beam is usually greater than its width except in the case of wall-plates.

Planks are thin scantlings of any convenient width and length. The breadth of a plank is ordinarily not less than 4 to 6 times its thickness. The usual thickness of planks varies from ½ to 2, and is occasionally as much as 3 inches. Planks are used for walls, floors, or ceilings, and by themselves, or in combination with other materials, as roof coverings.

For beams, only such woods as have a high modulus of elasticity should be used. It does not matter if they split or warp slightly in the process of seasoning, nor is it necessary that the grain should be quite straight.

For planks, a wood which seasons well, does not warp, and has a *straight grain* (*i.e.*, one in which the course of the annual rings is straight, not wavy), is necessary. Woods which are not sufficiently strong for beams will often make very good planks, as in the latter case strength is not of so much importance as a straight grain and good seasoning properties

For the construction of doors and windows, and in joinery generally, only woods that season well and are not affected by damp and drought should be used.

For ornamental purposes, strength is of very little importance: what is wanted in this case is a prettily-marked grain.

Wood with a beautiful grain is obtained chiefly from trees which have either very pronounced, very large, or very numerous medullary rays. If blocks of such trees are cut up into planks, so that the saw-cut makes a very small angle with the direction of the medullary rays as seen on a cross-section, the resulting plank will be very beautifully and irregularly marked

owing to the medullary rays having been cut through obliquely. Roots of trees, and trees (for example, many species of maple) which exhibit irregularities in growth consequent generally on injury either by insects or birds, also exhibit a beautifully marked grain. In some trees, the zone of wood formed in the spring is of a different colour to that made in the autumn. Advantage is taken of this fact in order to obtain prettily marked planks.

The harder and tougher a wood is, the more expensive will it be to work up. In consequence, especially hard and strong woods are only used for beams where great strength is necessary. For ordinary purposes, a moderately strong and fairly soft wood is preferable on account of the cheapness and ease with which it can be converted and worked up. If woods which are not strong are used for beams, the dimensions of the beam must be increased in proportion as the strength of the wood decreases.

§ 49. Only carefully seasoned timber should be used in buildings wherever it is possible to get it; scantlings with much sapwood should be rejected. Carefully seasoned wood will be found to be very much more durable than wood cut fresh from the tree. Freshly cut wood has another disadvantage, in that the process of seasoning will go on after it has been placed in position, with the result that it will warp and swell. Unseasoned wood is always liable to contract in hot, dry weather, as well as to absorb moisture and expand in damp weather.

Unseasoned timber is largely used in building construction in India, and this procedure accounts for the difficulty generally experienced in getting doors and windows to open and shut properly.

The practice of using unseasoned timber in buildings, bridges, and any other than temporary works, cannot be too strongly condemned.

Wood for the construction of doors and windows, which require to fit accurately, should not only be seasoned but should be dry.

§ 50. CAUSES OF DECAY.—If wood is kept constantly dry, or only affected by the moisture existing in the air, it will last for a long time. Some of the materials contained in the wood of

a tree are soluble in water, and when all these have been extracted, water no longer affects the remaining portions of the wood so long as it is totally immersed. This accounts for the extreme durability of some woods under water, as for example in the foundations of a bridge. If, however, wood which has been long immersed be taken out and dried, it will be found to be brittle and useless.

The principal causes of decay are—

(1) the presence of sap containing proteid substances,
(2) exposure to alternations of wetness and dryness,
(3) moisture accompanied by heat, and bad ventilation.

By *decay* or *rot* we understand the decomposition and partial or total consumption of the tissues of which the wood is composed. The sapwood, which contains more albuminoid materials than the heartwood, is the most perishable part of the tree. Decay is due principally to the attacks of fungi and of insects.

Fungi.—The number of different species of fungi which can draw nourishment from, and in so doing destroy wood, is very considerable, though the number of species which *beyond all doubt* are capable of attacking the woody portions of living trees is comparatively small. There are two principal kinds of rot, generally speaking, called *wet rot* and *dry rot*: the former occurs in the forest and in well ventilated places; the latter only in ill-ventilated places and in dead wood. In building construction it is dry rot that concerns us most, since the decay occurs after a beam has been placed in position in the building. It usually begins in the sapwood if present, and very often at the points where the timber is built into walls, and is often due to the lime in the mortar not having been properly slaked. Iron, lead, or zinc coverings to the ends of beams built into walls may prevent this. To detect dry rot in the absence of fungi or other outward sign, the best way is to bore a hole with an augur. A log, apparently sound as far as external appearances go, may be full of dry rot internally, and this can be detected by the dust extracted by the augur,

and more especially by the smell. If a piece of sound timber is lightly struck with a key or scratched at one end, the sound can be distinctly heard by a person placing his ear at the other end, even if this beam is 50 feet long; but if the beam is decayed, the sound will be very faint or unheard. Free circulation of air around the ends of beams embedded in masonry is one of the best preventatives against rot entering at the ends of a beam the surface of the beam in contact with the mortar should, from this point of view, be as small as possible.

Insects.—In tropical climates, timber is very liable to be attacked by white-ants (*Termes* sp. sp.).* The best way to prevent the ravages of white-ants is to see that none exist on the area to be occupied by the building. If any white-ant burrows exist, they should be dug out and the queen or queens destroyed. If this operation is carefully done, there is very little chance of white-ants appearing in the construction built on the ground thus treated.

Spon recommends that posts exposed to the attacks of white-ants should have a hole bored at a height of 6 inches above the ground line, which, after the end of the post has been charred for ten minutes to drive off the moisture, should be filled with boiling tar, and the tar forced into the pores of the wood by hammering a closely fitting peg into the hole.

Crude kerosene oil is equally effectual, and soaks through the wood better than tar, while the hole can be refilled at stated intervals. Kerosene oil can often be obtained in India where tar cannot be purchased.

Two experiments made in Burma tend to prove that white-ants may be driven from a building by pouring down their runs, a solution of "jungle exterminator." (*P. J. Carter.*)

White-ants are, however, much less harmful than is usually supposed, provided the timber consists entirely of heartwood of certain good species, as for example Teak (*Tectona grandis*), Sál (*Shorea robusta*), Deodar (*Cedrus Deodara*), or Padauk (*Pteocarpus indicus*).

Even if a construction must be built as cheaply as possible, it is advisable to make the foundations of masonry, as white-ants do not make their way through masonry or brickwork, although they may work round it.

§ 51. PRESERVATION OF TIMBER.—Timber may be preserved either by taking natural precautions, or by having recourse to artificial means.

Natural precautions.—To preserve wood from *decay*, it should be kept constantly dry and well ventilated; should not be in contact with damp earth or damp walls; and, as far as possible, should be free from contact with mortar, which hastens decomposition. Some woods suffer more from contact with mortar or cement than others. Thus, Pyingado (*Xylia dolabriformis*), the Burmese ironwood, is much more durable for sleepers than teak, but when used for posts in contact with mortar or cement the latter is less liable to rot. Wood kept constantly under water is often weakened and rendered brittle; but there are some woods, as Semul (*Bombax malabaricum*) that are durable in this position, though not otherwise. Wood that is kept constantly dry is usually durable, but after a great number of years becomes brittle. When wood is exposed to alternations of wet and dry it soon decays; some kinds much more rapidly than others. Chir (*Pinus longifolia*) and sundri (*Heritiera Fomes*) are marked example of this.

Moisture may be prevented from rising in the walls from the foundations by the interposition of a layer of some substance impervious to water, such as asphalte or Portland cement, through the thickness of the wall, a few inches above the ground.

Walls should be allowed to dry for some time before the woodwork is put into position. As quicklime, even in small quantities, accelerates decay, great attention should be paid to the proper slaking of the lime used in the mortar.

Artificial means.—Wood, when thoroughly seasoned, may be materially preserved by the application of *paint* or *tar* both of

which form a covering impervious to water. These preservatives must only be applied to seasoned wood; as if applied to unseasoned timber they aid the process of decay rather than retard it.

The composition and application of paint and tar is described in detail in Section VIII, page 92, § 64, *et seq.*

Many other preservatives have been introduced with a view to increase the durability of timber, among which the most successful is probably *creosote* (one of the products of the distillation of tar). A solution of *silicate of soda* applied to the outside of wood materially increases its durability. The impregnation of wood by *sulphate of copper* has also been found effective. The majority of these preservatives require special apparatus for their application, and consequently are never likely to come into general use in India in ordinary building construction and therefore need only be mentioned.

SECTION VII.—SOME OF THE MORE IMPORTANT TIMBER TREES USED IN CONSTRUCTION IN INDIA.

§ 52. The information contained in this section is chiefly drawn from Brandis's *Forest Flora*, Gamble's *Manual of Indian Timbers*, and from notes kindly supplied by the author of the latter work. The values *e* and R are taken from the *Roorkee Treatise on Civil Engineering in India, Edition* of *1878*, and the value of P from Gamble's *Manual of Indian Timbers* and the *Roorkee Treatise.*

The timber trees of the different provinces are arranged alphabetically according to their scientific names (taken from Brandis's *Forest Flora of the North-West and Central India* and Gamble's *Manual of Indian Timbers*). The names given in Sir Joseph Hooker's Flora of British India, when they differ, are in some cases given in foot-notes.

A table at the end of this section (pages 90 and 91) gives the *weights* of the different timbers, their *moduli of elasticity* (*e*), co-efficient of *transverse strength* (P), and the *resistance to crushing* due to direct thrust (R), as far as they are known,

The numbers given in the first column of the table refer to the numbers given in the text to the timber trees described.

§ 53. The three best known timber trees of India are Teak (*Tectona grandis*), Sâl (*Shorea robusta*), and Deodar (*Cedrus Deodara*). Besides these three there are a great number of trees which are used locally to a greater or less extent in those parts of India in which they are found, but which, owing to their comparatively local distribution, are not much known outside the regions in which they are found.

The three trees named above will be first described from an engineering point of view only, and then the more important of the local timber trees will be shortly described under the provinces in which they are chiefly used.

1. TECTONA GRANDIS (*Teak*) is a moderately hard, exceedingly durable, fairly strong, moderately heavy wood. It does not suffer from contact with iron, and is not very liable to be attacked by white-ants. The sapwood is white; the heartwood is dark golden yellow or brown when freshly cut, and darkens on exposure to a deep mottled brown. The heartwood has a strong and pleasant aromatic fragrance, due to the presence of an essential oil which is a great preservative of steel and iron. This fragrance is retained for a long time, and is always apparent on a freshly cut surface. *Teak* seasons well, and does not split, warp, shrink, or alter its shape when once thoroughly seasoned. It is easily worked, and takes a good polish. The annual rings are distinctly marked by larger and more numerous pores in the spring wood. The medullary rays are short, moderately broad, and equi-distant. In India, *Teak* is used for every description of house building, as well as for bridges, sleepers, furniture, and shingles. The transverse strength of Teak is not so great as that of many other Indian timbers, but its durability, excellent seasoning powers, and the facility with which it can be worked, render it the most desirable timber in India. The strongest *Teak* comes from South India: Burmese *Teak* is

softer, more even grained, and grows to a larger size. In Burma, *Teak* is transported chiefly by being drifted in the log down the smaller streams, and floated in rafts down the larger rivers to Rangoon, Moulmein, and other sea-ports, where it is converted to suit the requirements of the market.

2. SHOREA ROBUSTA (*Sál*) is a hard, strong, tough, durable, heavy wood. It is only slightly attacked by white-ants. The sapwood is greyish in colour and not durable; the heartwood is brown and hard, and has a remarkably fibrous, cross-grained structure, so that when the wood is worked up and polished, the fibres appear to interlace. *Sál* does not season well; it often warps and splits in drying, and, even when thoroughly seasoned, absorbs moisture in large quantities in wet weather unless carefully protected. While seasoning, the surface dries rapidly, while the interior remains as full of moisture as when first cut, and this water is given off very slowly. When thoroughly seasoned, it is a very strong, elastic, and durable wood. Concentric rings are sometimes clearly visible; these may or may not coincide with the zones of annual growth of the tree. The medullary rays are uniform, moderately broad, straight, and very prominent. *Sál* is the most extensively used timber in Northern India. It is used for piles, beams, planking, railings, and in the construction of bridges, as well as for doors, window-frames, posts, and rafters, and practically for any purpose connected with house-building, and especially for sleepers. On account of its weight *Sál* cannot be extracted by floating without the assistance of bamboos or some lighter wood.

3. CEDRUS DEODARA[1] (*Deodar*) is a light yellowish brown, very durable, strongly scented, moderately hard, rather brittle, and fairly heavy wood. The very characteristic and lasting scent of the wood is due to the presence of an essential oil which is chiefly confined to the heartwood. The wood darkens very considerably with age, but does not lose its characteristic odour. Its transverse strength is small. The sapwood is

[1] Cedrus Libani, *Barrel* var Deodara, *Hook. f. Fl. Br. Ind.*

narrow in old mature trees and it is whitish in colour. *Deodar* seasons very easily and well, and does not crack or warp after it has been once seasoned. The annual rings are very distinct, and are marked by a narrow belt of firmer and darker tissue. *Deodar* is the principal timber of the North-West Himalaya, and is by far the most durable of the Himalayan coniferous woods. It is extracted very largely in the form of railway sleepers. The sleepers are, where practicable, floated down the streams either in log, or, what is preferable, after conversion into sleepers or scantlings. As in the case of teak, immersion in water does not seem to affect the durability of the wood. *Deodar* is largely used for beams and planks, both in house construction and in bridges. It also furnishes good and durable shingles. Owing to its small transverse strength, the dimensions of the beams to support a given weight have to be considerably greater than those of *Sál* or other harder and tougher woods. In Lahore, it is largely used for furniture of all kinds.

THE NORTH-WEST HIMALAYA AND THE PUNJAB.

§ 54. The more important of the timber trees used in these Provinces are—

4. ABIES SMITHIANA (*Rai*), and 5, ABIES WEBBIANA (*Morinda*) are both used for planking when *deodar*, *chir* (*Pinus longifolia*), or *kail* (*Pinus excelsa*) cannot be procured; the wood of these firs is whitish in colour, and there is no marked difference between the heart and the sapwood. When protected from the weather, they are fairly durable, *Rai* being better than *Morinda*. The wood of these firs contains very little resin indeed. Both these timbers are used for temporary constructions in forest works; that of *Morinda* is sometimes used for shingles.

6. ACACIA ARABICA (*Babul*) yields a hard, heavy, very durable wood. The sapwood is large and whitish, the heartwood when cut freshly is light pink, which soon turns

to reddish brown with darker streaks; the medullary rays are numerous. It is used largely for the axles of wheels, well-curbs, agricultural implements, and tool handles. In Sind it is used for rafters, boat building, and occasionally for sleepers.

7. ACACIA MODESTA (*Phulai*) yields a prettily marked, strong, durable, and very hard wood. The sapwood is large, white, and perishable; the heartwood is dark brown with black streaks. *Phulai* is used for cart wheels, Persian wheels and agricultural implements.

8. ADINA CORDIFOLIA (*Haldu*) has a yellow wood which, when seasoned, often becomes reddish brown in colour. It has a compact and fine grain, but no distinct heartwood. The wood is fairly durable when protected from the weather. It grows to a large size, and is common in the Kamaon Bhâbar. The wood seasons well, works easily, but is somewhat apt to crack and warp. It is not attacked by white-ants or other insects, probably on account of its bitter taste. It is extensively used in construction both for beams, planks, and panels, as well as for furniture.

9. ANOGEISSUS LATIFOLIA (*Bakli* or *Dhau*) yields a light greyish brown, close and even grained, hard, very tough, elastic wood, the sapwood in young branches being yellow. The annual rings are marked by darker lines. The wood warps and splits in seasoning, and unless kept dry is not very durable. It is used for building native houses, for axe-handles, for poles for carrying heavy weights, the axles of native carts, and for shafts of carriages.

10. CEDRELA TOONA (*Toon*) is the "red cedar" of commerce; it yields a soft, red, shining, open-grained, fragrant, brittle, fairly heavy, durable wood, which is not much attacked by white-ants. The sapwood is narrow and of a much lighter colour. It is very easily worked, and seasons quickly and well. The annual rings are distinctly marked by a belt of large and numerous pores. It is used very largely for furniture of all kinds, as well as for door panels, door and window frames and carving. In Assam and Bengal it is used very largely for

tea boxes and packing cases. It is not used for beams or scantlings.

11. DALBERGIA SISSOO (*Sissoo*) is a very strong, tough, moderately heavy, very hard and durable wood. The sapwood is small in mature trees and white, the heartwood being brown with darker longitudinal veins. The wood is close and even grained. *Sissoo* seasons very well, and neither warps nor splits.

Sissoo has a crooked habit of growth, and does not, as a rule, yield pieces of timber of sufficient size and straightness to yield large beams, but under certain circumstances, as in close forest, it grows fairly tall and straight. The annual rings are not distinctly marked in the heartwood, but are more distinct in the sapwood. It is used for all purposes where strength and elasticity are required, and is lighter than sâl and nearly as strong. *Sissoo* is extensively used for the construction of wheels, agricultural implements, carts and carriages, and for tables, chairs, and furniture generally, as well as for carving. It is the best wood for the felloes and naves of wheels, and yields good sleepers.

The rapidly grown timber of canal or irrigated plantations is not nearly so durable as that which is grown more slowly in natural forests.

12. JUGLANS REGIA (*Akrôt*, Walnut) furnishes a dark brown wood, which seasons well, has a pretty grain, takes a fine polish, and is suitable for furniture and door panels.

13. LAGERSTROEMIA PARVIFLORA (*Dhauri*) gives a light-brown or yellowish wood, often with a reddish tinge, mottled, smooth and even grained. The heartwood is darker but not sharply defined. The wood is elastic, tough, and of great transverse strength. It seasons well, works freely, is fairly durable, and takes a fine polish. It is extensively used in construction.

14. MANGIFERA INDICA. The *mango* has a grey, soft, open-grained wood, with no distinct heartwood ; it seasons

readily and well; the annual rings are not distinct. It is largely used in Dehra Dún District for tea boxes, planks, doors and window frames; it is sometimes stained to imitate toon.

15. PINUS EXCELSA (*Kail*) furnishes a light, moderately hard, fairly durable, straight-grained wood. The sapwood is white, the heartwood being of a pretty light pink colour. Like *chir*, it is fairly durable if protected from the weather. The wood contains a good deal of resin, but not so much as *chir*. As is the case with most of the conifers, *kail* seasons well and quickly, and is easily worked. The annual rings are distinctly marked by an outer belt of darker and denser tissue. The wood is used for planking and in house building, and in Kulu for shingles, wooden spades, and other implements. At present it is difficult to get kail free from knots, but as it grows naturally in dense thickets, this difficulty should be only transient.

16. PINUS LONGIFOLIA (*Chir*) is a soft, light yellow, straight-grained, moderately heavy, but rather brittle wood. It is not durable. It is attacked by insects and decays rapidly if exposed to wet; but if protected from the weather, as in the interior woodwork of a house, will last from 15 to 20 years. The wood—especially the sapwood—contains a considerable quantity of resin. It is very easily worked, is much softer, and has a coarser grain than Deodar. The sapwood, which is whitish in colour, is about 2 inches thick in mature trees. *Chir* seasons well and quickly. If unseasoned, the wood contracts and expands very considerably with changes of weather. The annual rings are very distinct and consist of an inner belt of soft, and an outer darker belt of harder tissue. *Chir* is now being largely exported in scantling for use in the construction of native houses; it is also extracted as sleepers, which are sometimes passed off by contractors as deodar. The demand for small scantlings of *chir* has only sprung up during the last few years. Fairly good furniture can be made from it.

17. PISTACIA INTEGERRIMA (*Kakar*) yields an ornamental bright yellow wood streaked with black, which is very suitable for cabinet work.

18. PROSOPIS SPICIGERA (*Jhand*) yields an extremely hard, tough, coarse, open-grained wood which is not durable, as it is liable to attacks of fungi as well as of insects. The sapwood is white and perishable, the heartwood purplish brown. It is used in building, as well as for carts, well curbs, and agricultural implements.

19. QUERCUS SEMECARPIFOLIA (*Karshu*) yields a strong, tough wood, suitable for beams for houses and bridges. It does not season well.

NORTHERN AND CENTRAL INDIA.

§ 55. 20. CHLOROXYLON SWIETENIA (*Satinwood*) yields a very hard, fragrant wood, with a beautiful satin-like lustre. The wood is yellowish in colour, and has no distinct heartwood. The annual rings are distinct, and the wood seasons well. It is used for agricultural implements, and in cart-making, and makes beautiful furniture and picture frames.

21. EUGENIA JAMBOLANA (*Jaman*) produces a fairly tough, moderately hard, fairly durable wood. The wood is reddish grey : the annual rings are visible. The wood warps in seasoning, but does not split, and is very durable under water. It is used for building purposes, agricultural implements and carts, as well as for well curbs and steps.

22. HARDWICKIA BINATA (*Anjan*) is a very hard, very heavy, extremely durable wood, with a cross and very close grain. The sapwood is small and whitish, the heartwood dark-reddish brown, sometimes nearly black. It does not warp, but is liable to split. It is used for beams of bridges, beams and scantlings of houses, and for ornamental work. It is very difficult to cut up, and for this reason is not much used for sleepers.

23. PTEROCARPUS MARSUPIUM (*Bijasál*) yields a durable, very hard, strong and tough wood. The sapwood is small and whitish in colour, the heartwood is dark brown and contains a large quantity of a resinous gum which, when the

wood is damp, leaves a yellow stain. The wood seasons well and takes a fine polish. It is used for furniture, door and window frames, as well as for posts and beams, and is highly valued for carts, boat building, and agricultural implements generally. It is considered the next best wood to teak and Blackwood (*Dalbergia latifolia*) in the peninsula of India, where it is a common tree.

24. TERMINALIA TOMENTOSA (*Sain*) yields after *sál* the best building timber of these regions. The sapwood is reddish white, the heartwood is dark brown with streaks of a darker colour. The wood is heavy, hard, strong and tough, and seasons fairly well. Exposed to the sun it splits up rapidly. Its durability is variable. The wood is not so durable as that of *sál*, and is much attacked by insects and fungi. It is used largely in house building in the form of beams and scantlings, as well as for the construction of carts, etc. The wood is liable to split, warp, and shrink. It has been used for sleepers, but is not very satisfactory for this purpose.

Besides the trees described above, there are many other species which yield timber which can be used in building construction. Among these may be mentioned ALBIZZIA LEBBEK, *Siris*; GARUGA PINNATA, *Kharpat* or *Kitmira*; STEREOSPERMUM SUAVEOLENS *Padal*; GREWIA SP. SP. *Dhamin*.

BENGAL AND ASSAM.

§ 56. SHOREA ROBUSTA, *Sál* (page 76) is the best known timber tree of these provinces; besides *sál* the following trees are largely used. CEDRELA TOONA, *Toon* (page 78) and DALBERGIA SISSOO, *Sissoo* (page 79) are also largely used in these provinces.

25. CHIKRASSIA TABULARIS (*Chittagong wood. Beng. Chikrassi*) yields wood suitable for furniture and carpentry.

26. GMELINA ARBOREA (*Gamhar*) yields a soft, light, strong and durable wood. The wood is whitish in colour and close grained. The annual rings are marked by more

numerous pores in the springwood. The wood seasons well and does not crack, warp, or shrink. It is easily worked, and takes paint or varnish readily. It is durable under water. It is not attacked by white-ants, but is liable to dry rot. It is used largely for planking, furniture, door panels, carriages, well-curbs, and is in great demand for carving.

27. HERITIERA FOMES (*Sundri*) is found in the tidal forests of Bengal, Burma, and the Andamans. It is a durable, heavy, extremely tough, very hard, close-grained wood. The sapwood is white, the heartwood dark red. It shrinks considerably in seasoning. It is used for a great variety of purposes, such as beams, buggy shafts, planking, posts, furniture, and considerably in boat building, but has to be protected from the ravages of marine insects. It is the toughest wood in India.

28. LAGERSTROEMIA REGINÆ (*Jarúl*, the *Pyinma* of Burma) has a light red, hard, shiny wood, the annual rings being marked by a belt of larger pores. It is the most valuable tree in Sylhet, Cachar, and Chittagong, and is used in ship-building, all kinds of construction, as well as for carts. In Burma it comes next to *teak* in value, but is more suitable for interior work than for use in exposed situations.

29. MESUA FERREA (*Nageshwar*, the *Gangaw* of Burma) yields a very durable, heavy, rather brittle, extremely hard wood. The heartwood is dark red. The extreme hardness of the wood renders it very difficult to work, and so prevents its being more generally employed. It warps and splits when cut into planks or small scantlings. The heartwood is not attacked by insects of any kind. It is used in building construction, for beams of bridges, and tool handles.

NORTH-EAST HIMALAYA.

§ 57. In the hills of the North-East Himalaya, the chief local timber-producing trees, besides SHOREA ROBUSTA, *Sál* (page 76) and CEDRELA TOONA, *Toon* (page 78) are—

30. MICHELIA EXCELSA (*Champ*) which produces a light,

very durable, straight-grained, fairly strong wood. The sapwood is small and white, the heartwood when freshly cut is of a yellowish-green colour, which darkens on exposure to an olive brown. The wood seasons very well, and neither cracks nor warps. The annual rings are distinctly marked by the firmer layer of wood produced in the autumn. It is very largely used for planking, furniture, and small scantlings, and is one of the best woods for these purposes in the Darjeeling district.

31. QUERCUS LAMELLOSA (*Bûk*) is one of the most important trees in the Darjeeling district. The wood is hard, heavy, durable, strong, cross-grained, and tough. The sapwood is small and whitish in colour, the heartwood is greyish brown, and shows a beautiful silver grain on a radial section. The annual rings are not distinct; the medullary rays are very large and marked. The wood seasons fairly well, does not split but is apt to warp. It is used very largely in the construction of houses and bridges, for beams, door-posts, window-frames, and scantlings of all sizes. It is attacked by fungi.

32. SCHIMA WALLICHII (*Chilauni*) is found in the Lower Darjeeling hills, and yields a moderately hard, tough, durable, straight-grained, strong wood. The wood is dark reddish-brown in colour. The wood shrinks and warps consideablyr in seasoning. It is used for the beams of houses and bridges, and in Assam for planking, and has been tried for sleepers.

BURMA.

§ 58. After Tectona grandis, *Teak* (page 75) and LAGERSTROEMIA REGINÆ, *Pyinma* (page 83), the chief timber-producing trees are the following—

33. DIPTEROCARPUS ALATUS (*Kanyin*). The heartwood is reddish grey, moderately hard, smooth, and mottled. It is used in house-building and for canoes, but is not durable.

34. DIPTEROCARPUS TUBERCULATUS (*In*) yields a moderately hard, rough grained wood. The heartwood is reddish grey in colour. The wood is used for house-building, planks

and canoes in Burma. It should not be used where it will be exposed to the weather.

35. HOPEA ODORATA (*Thingan*) yields a very durable, hard, close, even-grained, tough, fairly heavy wood. The colour of the wood is yellowish brown, and it contains a yellow resin. It is the chief timber tree of Southern Tenasserim, and is used for house-building as well as canoes and cart-wheels.

36. PTEROCARPUS INDICUS (*Padauk*), which yields a strong, moderately hard, heavy, very durable, straight and close-grained wood. The sapwood is small, the heartwood dark red and slightly aromatic. It seasons well, is easy to work, and takes a fine polish. It is the most valuable wood produced in the Andamans, and is now being exported to England to be made into furniture. It is used for bridge and house-building, for furniture and carts, and yields good planks.

The Andamans wood is on the average just as heavy as that produced in Burma. The heartwood is not attacked by white-ants. According to Lazarus and Co. of Calcutta, it is very hard to polish. It is a splendid wood for building purposes, as it neither shrinks, warps, or splits. It is the only Indian wood which can be used instead of ash (*Fraxinus excelsior*) in gymnasiums. The wood is largely used for shingles in the Andamans. (*C. G. D. Fordyce.*)

37. SHOREA OBTUSA (*Thitya*) has a heartwood of the same colour as *Sál* (page 76), which is very hard and durable. The wood is more even grained than either *Sál* or *Ingyin* (see below), and is used for the construction of canoes, in building and also for tool handles.

38. SHOREA SIAMENSIS (*Ingyin*) has a very hard, very heavy, cross-grained heartwood, similar in colour and structure to that of *Sál* (page 76). The medullary rays are fine, numerous, and equi-distant. It is used extensively in Upper Burma in buildings and bridges.

39. SHOREA STELLATA (*Kaunghmu*) has a hard, rough whitish wood, which is used in making canoes and boats in Tenasserim.

40. XYLIA DOLABRIFORMIS (*Pyingado*) yields a heavy, close-grained, extremely hard, durable, strong wood. The sapwood is small; the heartwood is reddish brown and

beautifully mottled. The annual rings are indistinct. The durability of the wood is probably partly due to the essential oil which it contains, as well as to its extraordinary density. It is heavy and difficult to cut. It is extensively used for bridge-building, posts and piles, telegraph posts, and sleepers.

The difficulty in sawing up *Pyingado* is very much lessened if the logs are converted green, that is to say, immediately after felling. Sleepers so sawn are, however, apt to split, and are often protected from the sun by having straw thrown over them to prevent rapid drying (see also page 61). (*C. E. Muriel.*)

Besides the above there are many other valuable timber trees in Burma, about which comparatively little is yet known.

SOUTHERN INDIA.

§ 59. *Teak* (page 75) is the principal timber tree of Southern India; after it come PTEROCARPUS MARSUPIUM (page 81), XYLIA DOLABRIFORMIS (page 85), TERMINALIA TOMENTOSA (page 82), ANOGEISSUS LATIFOLIA (page 78), CEDRELA TOONA (page 78), HARDWICKIA BINATA (page 81), and MESUA FERREA (page 83), all of which have been described above. Of the trees which are peculiar to Southern India, the following are the most important:—

41. ARTOCARPUS INTEGRIFOLIA, the cultivated *Jack fruit tree;* and 42, ARTOCARPUS HIRSUTA. Both species yield moderately hard, yellowish-brown woods which season well and take a fine polish. The annual rings are indistinct. The wood is used for carpentry and furniture, as well as for house-building.

43. BORASSUS FLABELIFORMIS, the *Palmyra Palm*, is very widely used in Southern India for rafters. The rafters are cut from the outer portions of the stem, when the wood of the tree has become black; when it is young it is white, mottled with black. The wood obtained from the outer portion of an old tree is heavy and durable.

44. DALBERGIA LATIFOLIA (*Blackwood*). This is a fine-grained, hard, strong, heavy wood. The sapwood is large and whitish, the heartwood dark purple with black streaks. There are no distinct annual rings. It is used for furniture, cart-wheels, agricultural implements, and gun-carriages, as well as for combs and carving.

45. LAGERSTROEMIA MICROCARPA[1] (*Benteak*) yields a wood *similar* in properties to *jarul* (page 83.) The wood is red in colour and moderately hard. It is much used in building, construction, and also for furniture.

46. PTEROCARPUS SANTALINUS (the *Red Sanders*) yields an extremely hard, heavy, fine-grained wood. The sapwood is white, the heartwood purplish black, but when freshly cut, it has a blood-red colour. It is used largely for verandah posts, rafters, and agricultural implements, also as a dye-wood.

BOMBAY.

§ 60. In the Bombay Presidency all buildings, with very few exceptions, are erected by the Public Works Department, and *Teak* (page 75) either from Moulmein or that locally grown, is almost exclusively used. In the Kathiawar District, LAGERSTROEMIA MICROCARPA, *Benteak* (page 87) is a good deal used; and occasionally woods from the Malabar coast are utilized.

OUGEINIA DALBERGIOIDES (*Tinas, Sandhan*) is an important wood in this Presidency, being unrivalled for cart and carriage poles. EUGENIA JAMBOLANA. (*Jambhul*) (page 81) is much used for well-curbs. ACACIA CATECHU (*Kheir*) is used for constructions in the sea and in brackish waters, and is said not to be attacked by the *Teredo navalis.* ADINA CORDIFOLIA (page 78), STEPHEGYNE PARVIFOLIA, and THESPESIA POPULNEA, are also used in the construction of buildings by the Natives.

§ 61. In India, BAMBOOS are extremely important in all buildings of a small size. They are used for rafters, wall-plates, walls in small houses, and largely in the construction of light bridges, and similar works of a temporary nature. The most widely distributed bamboos are *Dendrocalamus strictus* and *Bambusa arundinacea*, the latter being recognized by its thorns.

In Bengal, Burma, and Assam there are other kinds of bamboos of varying quality, which are practically used for the same purposes. One of the most extensively used bamboos in Burma is *Cephalostachyum pergracile*, the Burmese *Tinwa.* In Lower Bengal the best kind is *Bambusa Balcooa.*

Experience throughout India and Burma proves that the best way of protecting bamboos of all kinds from the boring insects to which they are peculiarly liable, is to immerse them

1 Lagerstrœmia lanceolata, *Wall.* in Hk. Fl. Br. Ind.

in water for a week or 10 days directly they are cut. The water probably washes off or kills the eggs of the insects (chiefly small beetles) which attack and do so much damage to them. Bamboos which have been floated are much less liable to the ravages of insects than those which have been transported entirely by land.

Experience in Madras shows that Bamboos cut when there is no moon are much freer from the attacks of insects than those which are cut in that part of the month when the moon is bright at night. (*A. W. Lushington.*)

§ 62. The following list gives the names of the woods in most common use for the purposes noted opposite to them. The description of the woods will be found on the preceding pages.

Large scantlings in houses and bridges, or where strong timber of large dimensions is required.—Teak, Sâl, Padauk, Jarúl, Benteak, Anjan, Pyingado, Deodar, Thingan, Bûk.

Smaller scantlings, rafters, door-frames, etc.—Teak, Padauk, Jarul, Sissoo, Benteak, Sain, Bijasâl, Chir, Sâl, Haldu, Dhauri, Jaman.

Planking.—Teak, Jarul, Padauk, Benteak, In, Toon, Deodar, Chir, Rai, Champ, Sâl, Haldu, Jaman.

Panels.—Teak, Padauk, Blackwood, Sissoo, Toon, Satinwood, Kakar, Haldu, Chir, Jaman, Bijasâl.

Furniture.—Teak, Padauk, Sissoo, Toon, Blackwood, Satinwood, Jack.

Native houses, Posts.—Sain, Bakli, Bijasâl, Sâl, Pyingado, Chir, Red Sanders, Rai, Kail, Deodar.

Rafters.—Sâl, Sain, Palmyra, etc.

§ 63. In the table on pages 90 and 91 the value of P, *the co-efficient of transverse strength*, is found from the following formula:—

$$P = \frac{W \times L}{b \times d^2}$$

where P is expressed in *pounds avoirdupois*—

W = the breaking weight, or the weight in lbs., which when placed on the middle of the bar, causes it to break.

L = the length of the bar between supports, in *feet*.

b = the breadth of the bar in *inches*.

d = its thickness in *inches*.

The modulus of elasticity E_d is obtained from the formula—

$$E_d = \frac{L^3}{b\,d^3} \times \frac{W}{x}$$

where L = the clear distance between the supports in *feet*,
b = the breadth of the beam in *inches*,
d = its depth in *inches*,
W = weight supported at the centre of the beam in *lbs.*,
x = the deflection of the beam in *inches*.

E_d is determined from the amount of deflection of a beam freely supported at its ends and carrying a weight at its centre. A *modulus of elasticity* is a number representing the ratio of the intensity of stress (of any kind) to the intensity of strain (of any kind) produced by that stress so long as the elastic limit (*i. e.*, the maximum intensity of stress that can be applied to the material without causing an appreciable permanent distortion) is not passed.

By *stress* is understood the forces which cause alterations of form, while *strain* is used to mean the alteration of form caused by the forces.

R, *the Resistance to crushing*, is the constant for each wood denoting the direct cohesion in lbs. per square inch obtained from the formula—

$$P = R \times A$$

where P is the weight *in lbs.* which would tear asunder a piece of timber whose transverse section has an area of A *square inches*.

P is the same as p of the *Roorkee Treatise of Civil Engineering in India*, Volume I, page 175, edition of 1878. The co-efficient K in the formula for strength of rectangular beams, of the table in *Molesworth's pocket book of Engineering formulæ*, pages 18 and 122 of the 21st edition, is equal to 3 P of this Manual.

R is the same as f_t of the *Roorkee Treatise of Civil Engineering in India*, Volume I, page 175, edition of 1878.

E_d is taken from the *Roorkee Treatise of Civil Engineering in India*.

E of *Molesworth's* elasticity tables in the work mentioned above is equal to 432 E_d.

Table to show the weight, modulus of elasticity (E_d) and transverse strength (P) and Resistance to crushing (R) of the most important Indian timber trees and other materials.

Number.	Scientific name of wood.	Page.	Vernacular name of wood.	Natural order.	Weight of a cubic foot. Dry	Green	Modulus of elasticity Ed.	Transverse strength P in lbs.	Resistance to crushing due to a direct thrust. R in lbs. per square inch.
					in lbs.				
4	Abies Smithiana	77	Rae or Rai	Coniferæ	26·32	...	...	...	...
5	" Webbiana	77	Morinda	Do.	31	...	...	440	...
6	Acacia arabica	77	Kikar or Babúl	Leguminosæ	49·54	69·72	4,153	875·884	16,815
7	" modesta	78	Phulai	Do.	55·69	...	...	...	...
8	Adina cordifolia	78	Haldu	Rubiaceæ	42·50	...	3,260	464·664	10,431
9	Anogeissus latifolia	78	Bakli or Dhau	Combretaceæ	57·65	75·80	5,033	752·780	21,115
41	Artocarpus hirsuta	86	Aini	Urticaceæ	34	...	3,905	744	15,070
42	" integrifolia	86	Kathal, Pilla, Halasu.	Do.	38·44	...	4,030	562·788	16,420
43	Borassus flabelliformis	86	Tâl	Palmæ	25·72	...	4,904	814·944	11,898
10	Cedrela Toona	78	Toon	Meliaceæ	33·36	36·45	3,126	400·500	9,000
3	Cedrus Deodara	76	Deodar	Coniferæ	32·38	...	3,560	300·360	...
25	Chikrassia tabularis	82	Chikrassi, Gimmah, Agal.	Meliaceæ	43·49	...	2,876	614	9,943
20	Chloroxylon Swietenia	81	Bilgu, Burûs	Do.	51·61	70·75	4,163	600·1,000	11,369
44	Dalbergia latifolia	86	Shisham	Leguminosæ	50·60	64·70	4,053	950	20,283
11	" Sissoo	79	Sissoo	Do.	49	64·70	3,769	700·900	10,664
34	Dipterocarpus tuberculatus.	84	Eng, In	Dipterocarpeæ	45·55	...	...	750·758	...
33	" alatus	84	Kanyin	Do.	50	...	3,247	750	18,781
21	Eugenia Jambolana	81	Jaman	Myrtaceæ	40·58	63	2,760	600	8,840
26	Gmelina arborea	82	Gamhar, Gambari.	Verbenaceæ	30·40	...	2,132	324·675	...
22	Hardwickia binata	81	Anjan	Leguminosæ	67·85	100·120	4,957	942	12,016

27	Heritiera Fomes . .	83	Sundri . .	Sterculiaceæ .	65	104	3,726	710-1,200	29,112
35	Hopea odorata . .	85	Thingan . .	Dipterocarpeæ .	44-54	...	3,660	706-839	22,209
12	Juglans regia . .	79	Akrôt . .	Juglandeæ .	33-41	...	...	...	...
28	Lagerstroemia Reginæ .	83	Jarûl . .	Lythrarieæ .	38-45	...	3,665	650-800	15,388
45	„ microcarpa	87	Benteak . .	Do. .	40-48	...	...	542-939	...
13	„ parviflora	79	Dhauri . .	Do. .	40-50	...	...	467-757	...
14	Mangifera indica . .	79	Âm . . .	Anacardiaceæ .	38-44	...	3,415	450-650	8,810
29	Mesua ferrea . .	83	Nageshwa .	Guttiferæ .	64-74	...	...	994-1,053	...
30	Michelia excelsa . .	84	Champ . .	Magnoliaceæ .	33	...	...	...	...
15	Pinus excelsa . .	80	Kail . .	Coniferæ. .	26-33	...	...	...	...
16	„ longifolia . .	80	Chir . .	Do. .	27-41	...	4,026	550—750	...
17	Pistacia integerrima .	80	Kakar .	Anacardiaceæ .	54	...	...	...	...
18	Prosopis spicigera . .	81	Jhand . .	Leguminosæ -	58	82	...	...	...
36	Pterocarpus indicus .	85	Padauk . .	Do. .	43-71	...	4,180	620-1,033	19,036
23	„ Marsupium .	81	Bijasâl . .	Do. .	51-56	65-70	4,132	500-800	19,943
46	„ santalinus .	87	Lal Chandanum	Do. .	70-77	...	4,582	975	19,036
31	Quercus lamellosa . .	84	Búk . . .	Cupuliferæ .	59	...	...	...	...
19	„ semecarpifolia .	81	Karshu . .	Do. .	53-54	...	...	760	...
32	Schima Wallichii . .	84	Chilauni . .	Ternstroemiaceæ	43	...	...	383-760	...
2	Shorea robusta . .		Sâl . . .	Dipterocarpeæ .	56-64	75-80	4,586	300-900	14,982
38	„ siamensis . .	85	Ingyin . .	Do. . .	54	...	...	...	...
37	„ obtusa . .	85	Thitya . .	Do. . .	52-67	...	3,500	730	20,254
39	„ stellata . .	85	Kaunghmu .	Do. . .	47-50	...	...	...	...
1	Tectona grandis . .	.75	Sâgwan, Tekui Kyûn.	Verbenaceæ .	38-46	55-60	3,322[b]	470-600	15,482
24	Terminalia tomentosa .	82	Sain . .	Combretaceæ .	50-70	70-80	...	600-1,000	...
40	Xylia dolabriformis .	85	Pyngado . .	Leguminosæ .	58-75	70-80	4,283	693-1,153	16,657
...	Pinus sylvestris . M		Dantzic Fir or Pine.	Coniferæ .	40	...	4,219[a]	475	5,400
...	Quercus Robur . M		English Oak .	Cupuliferæ .	48-58	...	3,925	533	6,400
...	Wrought iron (average) M		......	......	485	...	57,685	2,844	37,856
...	Cast iron „ M		......	......	451	...	42,592	1,941	97,520
...	Steel „ M		......	......	499	...	67,130	...	336,000

M denotes that the values have been taken from Molesworth's pocket book of Engineering formulæ.
a. Notes on Building construction, Part III, page 404.
b. Pogson in Indian Engineering, February 3rd, 1894.

SECTION VIII.—PREPARATIONS FOR PRESERVING OR BEAUTIFYING WOODS.

§ 64. The chief materials in common use for preserving or beautifying woods are—

(1) Paint.	(3) Tar.
(2) Varnish.	(4) Putty.

(5) Linseed oil.

Paint and *Tar* are preservatives, while *Varnish* is used chiefly as a beautifier, as it brings out the grain of the wood. *Putty* is used to correct defects in wood previous to the application of the other preparations mentioned above; and also to fix panes of glass in windows, etc. *Linseed oil* applied to wood darkens and preserves it.

§ 65. *Paint* ordinarily used for the protection of wood or iron, consists of (*a*) a *base*, usually *a metallic oxide* in the form of a powder which constitutes with (*b*), the *vehicle*, a protective covering over the body to which the paint is applied. *Linseed oil* is the vehicle most commonly used. The durability of a paint depends largely upon the nature of the vehicle used. When it is found that the paint resulting from mixing the base with the vehicle is not sufficiently liquid, (*c*) a *solvent*, may be added so as to allow of the paint being spread easily and evenly over the surface to which it is applied. The solvent most generally used is *turpentine*. When it is essential that the paint should dry very quickly, (*d*) a *drier* may be added. Boiled linseed oil is in itself a drier. When a paint of any particular shade is required, a *colour* or *pigment* is added. When a light shade is wanted, the substance selected for the base should be either white or some light colour, so as not to mask the pigment added.

§ 66. Bases.—The substances most commonly used as bases are *white lead*, *red lead*, *oxide of zinc*, and *oxide of iron*.

White lead is a carbonate of lead and is a heavy white powder, which becomes grey on exposure to air; it is insoluble in water. White lead is sold in a powder, in lumps, or else

ground in oil, that is, thoroughly mixed with oil to form a paste composed of white lead, to which from 7 to 9 per cent. of linseed oil has been added. Paints ground in oil are liable to adulteration unless made by some well-known firm. Paint made from white lead improves by keeping so long as air is excluded. White lead paints are the best for the preservation of wood, as they are dense, of good body, and permanent. They are, however, commonly adulterated with barytes (sulphate of lead); the presence of this latter substance can be detected by digesting a small quantity of the powder in nitric acid. White lead is readily soluble on boiling the mixture, but barytes is insoluble. If the paint to be tested is ground in oil, the oil should be first burnt off.

If a pound of lead paint of good quality be calcined[1] it should yield half a pound of pure lead.

Red lead is an oxide of lead, usually of a bright red colour. It is sold dry or ground in oil or varnish. Paints made from it are durable, and unaffected by light if pure. Red lead is largely used for painting iron; it is also added to other paints as a *drier.*

Oxide of zinc is the basis of zinc paints; it is insoluble either in oil or water, but is easily dissolved in hydrochloric acid. It is wanting in body and covering power, is difficult to work; takes a long time to harden, weathers badly, being acted upon by the carbon dioxide present in the air, and is much affected by the organic acids which exist in unseasoned woods. It has no smell and washes well. Lead driers should not be mixed with it; sulphate of zinc or sulphate of manganese (1 ounce of the drier to 14 ℔ of the base) are the driers which, if required, are best suited for mixing with this base.

Oxide of iron is made from hæmatite, the ore being roasted, separated from all impurities and reduced to a state of powder. Paints made from this base are free from all injurious ingredients, and are particularly suitable for the painting of iron. Their cost is about the same as that of lead paints, but they are really cheaper, as weight for weight they cover a larger surface.

[1] Instructions for painting new and old iron and timber work for the use of the Bengal-Nagpur Railway (Indian Engineering, September 15th, 1894.)

§ 67. VEHICLES.—Vehicles are usually vegetable oils which do not evaporate on drying. *Linseed oil*, the one most commonly used, is expressed from the seeds of flax. *Raw linseed oil* of good quality is pale in colour, perfectly transparent, sweet in taste, and nearly free from smell; a dark colour and slowness in drying are signs of an inferior oil. *Boiled linseed oil* is thicker and darker in colour than raw linseed oil, it is used for external work as it has more body and dries more quickly. Raw linseed oil spread in a thin film upon glass, which takes from 2 to 17 days to dry, will, if boiled, dry in from 12 to 24 hours, according to the hygrometric state of the air.

§ 68. SOLVENTS.—*Turpentine* is the solvent most commonly added to make paints more liquid. It should only be used when the paint is too thick to be worked easily. Solvents, being volatile, do not add to the preservative qualities of the paint, and should be avoided as much as possible. A little turpentine will prevent a paint exposed to the sun from blistering. Turpentine is produced by distilling the resin exuded from certain conifers; when pure its specific gravity is 0·87, and its boiling point 160°c. It is a colourless liquid and has a pleasant pungent smell. It volatilizes on exposure to air, leaving, if impure, a resinous residuum. Good turpentine should evaporate if spread in a thin layer upon any substance in 24 hours. Commercial turpentine is often adulterated with mineral oils, such as petroleum (kerosene).

Pure turpentine distilled at the Imperial Forest School, Dehra Dún, from the resin which exudes from *Pinus longifolia and Pinus excelsa* has a specific gravity of 0·859, and boils at 163½°—166°C under a pressure of 760 mm. and at 28° Cent.

§ 69. DRIERS are substances added to paints to cause the oil (vehicle) used to thicken and solidify more quickly. They should not be used when the base and colour employed dry well in oil, nor should they be used in excess, as in that case they not only retard the process of drying but injure the resulting paint. They may be added to the oil used, in order to improve its drying qualities, or else they may be ground up in a small quantity of oil and added to the paint just before it is applied.

In India, boiled linseed oil added to raw linseed oil will usually be found sufficient for outdoor application. *Litharge* (an oxide of lead) is one of the substances most commonly used as a drier. *Red lead* may be used where the ultimate colour of the paint is not of importance; it does not cause the paint to dry so rapidly as litharge does.

§ 70. PROPORTION OF INGREDIENTS IN PAINTS.—The proportions in which the different ingredients which form paints are mixed, differ very much according to the use for which the paint is required and with the character of the climate. One gallon of paint should cover 500 sq. ft. of wood surface. The following tables, which are extracted from the instructions[1] for painting new and old iron and timber work, Bengal-Nagpur Railway, show the composition of paints which has been found suitable in India:—

Materials.	Composition.	AMOUNT REQUIRED TO COVER 100 SQUARE FEET OF SURFACE										
		New Timber work.			Old Timber work.		New Iron work.		Old Iron work.	
		1st coat.	2nd coat.	3rd coat.	1st coat.	2nd coat.	1st coat.	2nd coat.	1st coat.	2nd coat.
		lb oz.	lb oz.	lb oz.	lb oz.	lb oz.	lb oz.	lb oz.	lb oz.	lb oz.
Black paint	Ordinary moist.	4 0	2 2	1 2	3 4	2 9	3 4	1 12	4 1	2 8
White do	Ordinary moist white lead.	4 4	2 12	2 9	4 0	2 0	3 0	2 11	3 0	2 11
Slate do	18 lbs of white lead to 1 lb of lamp black.	4 4	2 12	2 9	4 0	2 0	3 0	2 11	3 0	2 11
Red lead do	Sold dry, needs more oil than the next shown in table.	4 4	2 12	2 9	4 0	2 0	3 0	2 11	3 0	2 11

[1] Indian Engineering, 15th September 1894.

The actual amount of oil and turpentine required to thin colours to a state ready for application, depends upon the state in which the moist colours (*i.e.*, paints ground in oil) arrive, and whether they have been kept in wooden casks or metal drums, and also upon how long and with what care they have been kept. If kept in wooden casks, leakage and absorption into the casks affects each one differently.

Paints intended for outside application require less boiled and more raw linseed oil than those prepared for inside application. Sufficient boiled linseed oil must be added, however, to ensure good standing powers. The following table shows the quantities of oil and turpentine recommended :—

Nature of work.	Lead paint white, red, or slate.	Boiled linseed oil.	Raw linseed oil.	Turpentine.
Inside work . . .	28 lb	5½ lb or 4⅝ pints.	5½ lb or 4¾ pints.	15 ounces or 1 pint.
Outside work . .	28 lb	4 lb or 3⅜ pints.	7 lb or 6 pints.	15 ounces or 1 pint.

		lb	oz.
Note.—1 gallon of boiled linseed oil averages . .		9	7
Do	raw do do . .	9	3
Do	turpentine	8	7

Paint mixed with boiled and raw linseed oil in equal quantities will set thoroughly hard in 24 hours in inside and much more quickly in outdoor work. For painting iron, if oxide of iron and linseed oil be used, they should be mixed in the proportion of two parts of oxide to one part of oil; 1 lb of oxide of iron will cover nearly 200 square feet of sheet iron.

§ 71. METHOD OF MIXING THE INGREDIENTS.—The colouring matter, if any be used, should be ground up in a little oil to a pasty mass. The base and the oil should be thoroughly mixed by stirring the base into the oil, and when this operation is complete, the pigment (colouring matter), if any is required, should be added.

The paint should be thinned to the required consistency by the addition of linseed oil, and, if necessary, a little turpentine just before it is applied. The paint should be sufficiently liquid to allow of its being spread evenly and easily on the surface, to which it is to be applied by means of stiff brush. The oil added must be well stirred into the paint to ensure of its being thoroughly mixed with the other ingredients of which the paint is composed.

As a rule native painters only use the hand or a bundle of rags for applying paint.

§ 72. APPLICATION OF PAINT.—Paint should be applied in fine weather. The material to be painted should be dry; it is not necessary that the air should be absolutely dry, but the paint should be applied, if possible, when the quantity of moisture in the air is decreasing. If the paint is too thick it cannot be worked thoroughly into the substance to which it is applied, nor will it lie evenly on that surface; if, however, the paint be too thin it will not have sufficient body, and will in consequence be wanting in durability and protective power. Paint should be applied with a stiff brush, the ends of the hairs of the brush only should touch the wood; the paint should be thoroughly forced into the pores of the wood, and should be laid on as evenly as possible. If two coats of paint are applied, the first coat should be perfectly dry before the second coat is added. If the paint is likely to be exposed to the sun, boiled linseed oil should be used, and the quantity of turpentine reduced. Only sufficient turpentine should be added as is necessary to make the paint work easily and prevent it from blistering.

If not used quickly paint thickens, and a skin forms over it. In order to prevent this, its surface should be covered with water or a thin layer of linseed oil when not in use.

§ 73. PREPARATION OF WOOD FOR PAINTING.—The wood should be thoroughly dry. The surface should be clean, smooth, and free from dirt. All nails should be punched in so that their heads are below the surface, and the holes left should be filled in with putty. All knots, especially those in resinous wood, should be *killed*, that is, cut out to a slight depth and filled in with a putty made of white lead and oil. If old work is to be re-painted,

the surface should be scrubbed with soap and water; to which washing soda (*Sodium carbonate*) may be added with advantage. If the surface is greasy or smoky, it should be washed with lime water and rubbed with sand paper. All cracks should be filled up with putty. If the old paint is much blistered, it should be entirely removed by scraping and burning, or else by using a solution made by dissolving 2 ounces of soft soap and 4 ounces of potash in boiling water, and by adding to it half a pound of quick-lime. This mixture should be applied while hot, and the old paint can be washed off after a lapse of from 12 to 24 hours.

§ 74. The following information with regard to painting in India has been taken from the Bengal-Nagpur Railway Circular above referred to (see page 95, § 70) :—

It is important that all paint should be thoroughly well mixed with oil before use. If this is not done the paint will consist of fine particles of colour each particle being coated with oil. The sun and air absorb the oil and leave only the dry colours to fall or rub off with ease. This mixing cannot be done thoroughly by any hand process, and for this reason unground or raw paints obtained from earths or ores in this country cannot be applied efficiently to bridges and other works far away from the necessary grinding apparatus. The use of ready manufactured moist paint (*i. e.*, paints which have been ground in a patent mill with oil, and only require thinning for use) is therefore very advisable both for efficiency and on account of the trouble saved in the operation.

Experiments made in other countries shew that lead paints are the most suitable and preservative for iron work. Either white or red may be used indifferently. The objections to their use is that they are expensive, and the colour of either alone is objectionable on large surfaces. Slate colour, composed of white lead and lamp black, is an efficient and economical substitute as it contains sufficient lead preservative, and black is the best of all standing colours, probably owing to its containing a certain amount of resinous matter which enables it to adhere to the work.

Too much attention cannot be paid to the thorough cleansing of any work, either wood or iron, to which paint is to be applied. Paint put on too freely, either too thick or too thin, will dry unequally and never come to a good surface, but will show up its irregular surface through the coats which follow. In painting new work the paint should be mixed a little thinner for the first coat than for those which follow. Wood work should stand unpainted for a year to allow of its seasoning thoroughly, as paint causes unseasoned wood to decay.

Driers such as litharge need not be used. Boiled linseed oil will give the necessary drying power. Boiled linseed oil should not be used in quantities more than requisite to ensure sufficient rapidity in drying. What is sufficient for drying is sufficient to give the necessary solidity and standing

power (durability) to outdoor work. This is better effected by raw than by boiled linseed oil owing to the superior elasticity of the former.

Outdoor work should not be finished *flat*. A flat coat (or one without gloss) is obtained by mixing a large amount of turpentine and very little oil with the paint. The turpentine evaporates speedily in the sun and leaves the dry paint to rub off with ease. Work finished flat is only admissible in interiors.

In addition to the actual paint the following materials are required:—

1. Paint brushes. Hog-hair for ordinary and sable for fine work.
2. Wire brushes, } for clearing iron.
3. Brick or sandstone, } for clearing iron.
4. Pumice stone for clearing new wood work.
5. Putty for stopping knots in wood work.

Painting wood work.

New wood work should first be thoroughly cleansed with pumice and dusted with a dry brush. The first or priming coat is then applied. The coat is mixed with oil only and should be mixed thinner than the succeeding coats as more oil is absorbed by the wood. When dry, all cracks, knots and shakes in the wood should be stopped (*i.e.*, filled up) with putty, and the 2nd and 3rd coats applied. Each coat should be allowed to dry before the next is applied.

Wood-work to be repainted should be also first thoroughly cleansed from dirt, and decayed paint with pumice and should then be well dusted with a dry brush before the new colour is applied. When it is required to entirely strip old paint, a painter's lamp should be used; this will soften the paint and allow of its being easily removed by a scraper.

Painting Iron work.

Iron work to be painted for the first time should be thoroughly cleansed from rust, etc., with wire brushes, soft bricks, and finally, dry brushes. When quite clean, it should receive a coat of new oil, slightly heated, and when this is dry a coat of prepared paint. When exposed to the sun its own warmth is sufficient to heat the oil. The priming coat for iron need not be thinner than the second coat. The latter should not be applied till the first is dry. Old iron work to be repainted should be brushed and cleansed of old decayed paint and rust as above described, and the colour applied in the same way.

Requisition for painting materials.

Two and a-half per cent. extra of raw linseed oil and turpentine should be ordered, and 5 per cent. of boiled linseed oil to allow for leakage. The boiled and raw linseed oil should be bought by the pound, the turpentine by the gallon.

One lb of pumice is required per 1,000 sq. ft. of woodwork to be painted. Two large round dusting brushes, $2\frac{1}{2}$ inches in diameter, should be indented for. The painting brushes should be of two sizes: large, oval, $2\frac{1}{8}$ inches by $1\frac{5}{8}$

inches, and smaller round ones, 1 to 2 inches in diameter. All brushes should be kept in water (covering the bristles) when not in use. Wire brushes should be ordered by number, pumice by the pound, and sand-paper by the quire; whiting for making putty by the pound. Putty for stopping wood-work should be made by mixing 1lb of whiting thoroughly with 3 ounces of boiled linseed oil.

§ 75. VARNISHES.—A varnish consists of a *base* which may be rosin or a gum and a *solvent* such as (1) oil, (2) turpentine, or (3) alcohol; the three last named bodies evaporate leaving a thin transparent film of the rosin or gum on the surface to which the varnish has been applied. The quality of a varnish depends upon that of its ingredients: a good varnish should dry quickly into a hard, tough, permanent glossy film. Varnishes are used to give brilliancy and protection to painted surfaces, and are also applied to unpainted wood to intensify and brighten the ornamental appearance of the grain. The substances most commonly used in making varnishes are: (*a*) *Colophany* or *rosin*, which is obtained from the distillation of the crude resin yielded by some of the pines. Colophany is obtained either as an almost transparent, colourless, yellow, or brown substance; it is very brittle. Gums, which exude from wounds made in the stems of certain trees are also used. *Amber*, a fossil gum, is the hardest and most durable of these. It keeps its color well, but is difficult to dissolve, expensive, and slow in drying. *Gum animé* which is nearly as insoluble, but not so tough, as amber, as well as *Copal*, *Dammar* and *Mastic* are also used.

Solvents.—Boiled linseed oil is the solvent for amber, gum animé, and copal, while *turpentine* is used to dissolve mastic, dammar, and rosin. Native varnishers are very apt to introduce *giri* (a thick red substance which entirely hides the grain of wood) into the varnish.

Alcohol in the form of *methylated spirit* may be used to dissolve colophany, but should not be used when the varnish is exposed to rain, as water falling on it turns it quite white.

Driers.—Litharge (an oxide of lead) and acetate of lead are

used to make the varnish dry more quickly, but if used in large proportions are injurious.

§76. OIL VARNISHES consist of amber, copal, or gum animé dissolved in oil; the gum is slowly melted alone until quite fluid, and the clarified oil is poured in very slowly, the mixture being kept over a fire. The mixing of varnishes requires a considerable skill. Oil varnishes require a considerable time to dry, but when dry are the hardest and most durable of all varnishes, and are suitable for out-door work.

TURPENTINE VARNISHES consist of soft gums or rosin dissolved in pure turpentine; they are cheaper, dry more quickly, and are lighter in colour than oil varnishes, but are not so durable or tough. They will not stand exposure to the weather, and are consequently unsuited for external application.

Turpentine varnishes are made by stirring the powdered rosin or gum into the solvent until the former is quite dissolved; gentle heat is sometimes necessary to make the rosin dissolve properly.

Four pounds of common rosin should be dissolved in one gallon of turpentine. A good turpentine varnish should dry so as not to be sticky in one or two days.

§ 77. APPLICATION OF VARNISHES.—If wood-work is to be varnished, a coat of *size* (see page 49, §39) should be first applied so as to fill up any little inequalities in the wood. Another good plan is to rub the surface to be varnished with a mixture of whiting (powdered chalk) and pure raw linseed oil; a rag is first dipped in linseed oil, then into the *whiting* (see page 103, §80) and applied to the surface to be varnished, the mixture being thoroughly rubbed into the wood. The whiting must not be first rubbed into the wood and the oil applied afterwards. By applying both together as described above, the grain of the wood is in no way hidden or coloured, but is on the contrary improved. No colouring should be added to the varnish. When the coat of size or whiting and linseed oil is quite dry the varnish may be applied. The surface of the wood must be quite clean, and the brushes used free from dirt. The varnish

should be applied uniformly in very thin coats, especially at the angles. One pint of varnish should cover 16 square yards of surface with one coat. One coat of varnish should be allowed to become quite dry and permanently hard before another is applied.

§ 78 TAR.—Tar may be obtained either from coal or from some species of the genus *Pinus* by destructive distillation. That made from coal is known as *mineral*, that from wood as *vegetable* or *Stockholm* tar. The preservative powers of tars are chiefly due to the creosote which they contain.

Application.—Tar may be applied to wood, stone, and other substances in a similar manner to paint; it should not be applied to unseasoned wood. The ends of pieces of wood which are to be embedded in masonry are commonly tarred to preserve them from decay. Tar is usually a very thick liquid, and before being applied should be either placed in the sun for several hours in order to make it more liquid, or else should be gently heated for a few hours before use, to allow of its being worked easily. If *colophany* (page 100, §75) or *pitch* (page 102, §79) is available, take 6 gallons of coal tar, add to it 1 pound of rosin and 1 pound of pitch, and boil them together; the mixture should be applied while it is hot and consequently more liquid. If vegetable tar is used, the rosin should be left out.

A good paint for coating iron may be made by mixing together—

9 gallons of coal tar,
13 pounds of slake' lime, and from
2 to 3 quarts of turpen ine.

The addition of the lime is nec ssary to neutralize the free acids which are present in the

§ 79. PITCH is obtaine f *methyla*getable tar by driving off by heat the water and pyrol not be acid which it contains. It is a solid, black, shiny resinous s on it nce, and is chiefly used for caulking (*i.e.*, rendering water- ht) the joints between

planks. The joints are first filled with hemp; melted pitch is then poured over them and allowed to dry.

§ 80. PUTTY is made of *whiting* (pure white chalk reduced to a very fine white powder), to which a little *white lead* (see page 92, §66), may be added. These substances are carefully dried and mixed with oil into a stiff paste. This paste should be well kneaded and left for 12 hours. White lead is added to make the putty hard and to give it additional strength when used for *glazing*, *i.e.*, fixing glass into window sashes. Putty should be mixed just before it is to be used; if it is put on one side for a time, it must be worked up again with fresh oil before use.

Proportions of ingredients.—Ten pounds of whiting, one pound of white lead, mixed with enough *boiled linseed oil* to bring it to a proper consistency, makes a good soft putty. If a harder putty is required, more white lead should be added. Hard putties must be painted quickly in order to prevent their cracking.

Use.—Putty is used for fixing panes of glass into windows, and also for filling up defects in wood, and holes made by nails in wood before paint is applied. In the former case, where the rebate of the sash is shallow, the proportion of white lead should be increased.

§ 81. LINSEED OIL.—Woodwork may be materially preserved by the application of linseed oil. The wood should be first thoroughly cleaned with soap and water, and when dry dusted with a dry brush. Raw linseed oil is then well rubbed in with rags dipped in the oil and left to dry. The finest polish can be effected by the frequent application of oil in this manner. Neither heat nor weather affect it. Boiled linseed oil should not be used.

CARPENTRY AND JOINERY.

SECTION IX.

10[illegible].—In building construction, scantlings of considerable length are often required which cannot conveniently be obtained in one piece, and in such cases two or more short pieces

may be joined together in order to make the beam or scantling of the required size. The arrangement of the timbers in order to obtain the beam of the required length or size is called a *joint*. Joints may be made in several different ways, depending upon the purpose for which the scantlings are required, and whether the appearance as well as the strength of the joint has to be considered. When scantlings are being joined, the following general principles should be remembered:—

(1) that the joints should be cut and the fastenings arranged so as to weaken the timber as little as possible;

(2) that each abutting surface should be placed as nearly as possible perpendicular to the pressure which it has to resist;

(3) that the area of the surface of each scantling should be proportional to the pressure which it has to bear; and

(4) that the surfaces brought together to form a joint should fit very accurately, so that all pressures and stresses (see page 120, § 99) may be distributed equally.

The simpler the form of joint the better: simple joints can be fitted very much more accurately and more easily than complicated ones; and if the surfaces brought together in the joint do not fit accurately, the advantages of the more intricate form of joint are to a great extent, if not entirely, lost.

§ 83. Joints may be classified according to the purposes for which they are required into—

(1) joints for lengthening pieces of timber supported at either end	lapping, fishing, or scarfing.
(2) for lengthening beams resting on other beams or walls	halving, notching, and cogging.
(3) for joining scantlings fixed at right angles the one to the other	mortice and tenon.
(4) for connecting scantlings inclined to each other at an angle other than a right angle	oblique tenon mitre joint.

A beam in compression is called a *strut* or *brace*; one in tension is called a *tie*. Posts supporting a verandah are examples of beams subjected to a compressive force. The tie beam of a king post truss is in tension, while the wall plates supporting the rafters which carry a roof are subjected to a transverse stress. The tie beam of a king post truss is subject to a transverse stress as well as to a tensile force. A beam is said to be subjected to a *shearing stress* when the effect of the forces acting on it is to tend to make it move over the beam to which it is fastened; for example, the lower ends of rafters tenoned into a tie beam have a tendency to spread abroad, the force which causes this motion or tendency to motion is called a shearing force (see also §99, page 118).

§ 84. LAP JOINT.—*Lapping* consists of laying one beam over another for a certain length and binding or bolting the overlapping portions together. The overlapping portions may be fastened together either by iron bolts passing through, or iron straps passing round the scantlings.

FIG. 25.

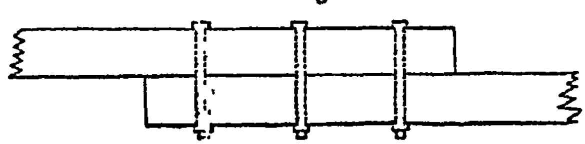


Figure 25 is an elevation of a lapped joint. The bolts which fasten the two pieces of wood together are shown in dotted lines and are not drawn to scale. Scale = $\frac{1}{20}$.

This is a clumsy-looking joint, but is stronger than any more artificially constructed beam of the same thickness.

§ 85. FISH JOINT.—One of the simplest and best ways of lengthening a beam is to bring the ends together, place plates of iron or wood (called *fish-plates*) on either side of them and fasten the beams and the fish-plates together by means of straps

or bolts. This kind of joint is not suited to resist a cross strain, as the strength of the joint will in that case depend upon that of the bolts or straps used. Figure 26 shows a simple fished joint.

FIG. 26.

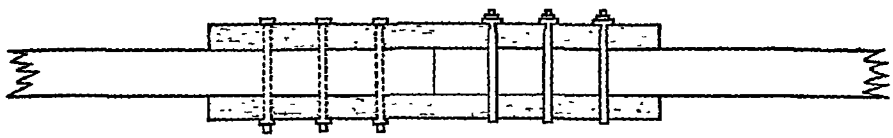


Figure 26 shows a simple fished beam in elevation; the fish-plates are of hard wood. The joint is shown fastened with bolts on one side of the joint and straps on the other. Scale = $\frac{1}{20}$.

A simple fished joint is the one best suited for lengthening beams in compression. In this case straps should be used so as not to decrease the strength of the beams. The dependence on the bolts or straps may be lessened by *indenting* or *tabling* the parts together, as shown in figure 27, or by inserting wooden *keys, vide* the same figure. Fish-plates should be applied to all four sides when the beam is subjected to compressive force.

FIG. 27.

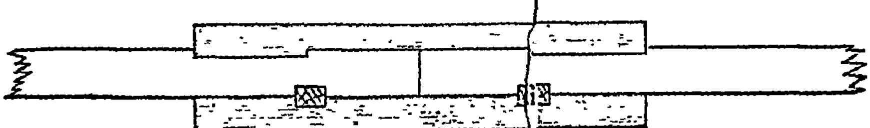


Figure 27 is an elevation of a fished joint, tabled on the upper side and keyed on the lower side; the bolts and straps have been omitted in the drawing. Scale = $\frac{1}{20}$.

These modifications of the simple fished joint decrease the strength of the beam in proportion to the depth of the indents made. If the wood shrinks very slightly and the bolts are not

tightened up, they no longer increase the strength of the joint. The sum of the areas of the bolts should not be less than $\frac{1}{6}$th the area of the *effective* section (the section with the smallest area) of the beam. The bolts should not be placed near the ends of the fish-plates; nor should they be placed in one and the same straight line, but *chequerwise* as shown in figure 28.

FIG. 28.

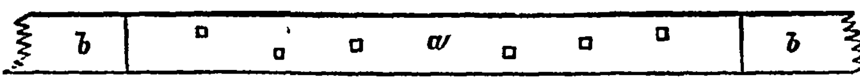


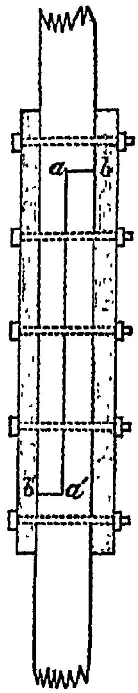
Figure 28 is the plan of a fished beam showing the chequer arrangement of the bolts on the fish-plate; a *is the fish-plate,* b *the beam. Scale*$=\frac{1}{20}$.

If iron *fish-plates* are used, a thickness of $\frac{1}{4}$th of an inch is generally sufficient. If a hard wood is used, the fish-plates should be $2\frac{1}{2}$ inches thick, and if a soft wood is used they should be still thicker.

§ 86. SCARF.—A scarfed joint presents a much neater appearance than either a fished or a lapped joint does, because the resulting beam is the same thickness as the two component ones. The joint is however not so strong as those described above. The simplest forms of scarfs are the best, as they can be more easily and accurately made. The bearing surface of indents which undergo compression should be perpendicular to the compressing force. Scarfed joints may be strengthened by the addition of fish-plates or hard wooden keys or wedges (see figures 30 and 31). The strength of *keys* or *wedges* should be proportional to the strength of the other parts of the joint.

The actual form of a scarf joint in any individual case depends upon the nature of the strain which it is required to bear.

FIG. 29.



SCARF TO RESIST COMPRESSION.—A scarfed joint constructed to resist compression is shown in figure 29. Such a scarf may be strengthened by the addition of fish-plates as shown in the figure, but these are not essential to the construction of the joint itself. The bearing surfaces, *a b* and *a′ b′* should be equal, as large as possible, and perpendicular to the compressing force. This joint is unsuited to resist a cross stress or a tensile force.

Figure 29 shows the elevation of a scarfed beam strengthened with fish plates, constructed specially to resist compression. Scale = $\frac{1}{20}$.

§ 87. SCARFS TO RESIST TENSION.—Figure 30 shows the elevation of a form of scarf commonly used in joining beams in tension; it is a difficult joint to make properly, and is not suited to resist compression as the indents are oblique.

FIG. 30.

Fig 30 shows in elevation a scarfed beam: a, a are wedges driven into the beam from either side to keep the joint from opening out. From Tredgold's Carpentry. Scale = $\frac{1}{20}$.

One of the scantlings is shaded to show the nature of the joint more clearly. The joint may be kept together by two wedges of hard wood (fig. 30), or else by a key, as shown in figure 31. This scarf is much strengthened by the addition of iron fish-plates, see fig. 33.

Figure 31 is the elevation of another form of scarf which is stronger and easier to make than the one shown in fig. 30. If wedges are used to complete the joint they should be only driven home sufficiently far to bring the surfaces of the beams which form the joint into their proper bearing. It is not necessary to have a key if bolts are added.

FIG. 31.

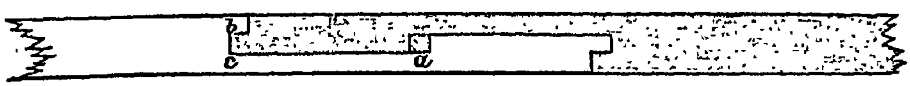


Fig. 31 shows in elevation a form of scarfed beam to resist compression and tension ; a is the key which keeps the joint tight. From Tredgold's Carpentry. Scale = $\frac{1}{50}$.

§ 88. SCARF TO RESIST TENSION AND COMPRESSION.—The scarfed joint given in figure 31 is adapted to resist compression as well as tension even without fish-plates; where the beam is in compression only, the scarf given in figure 29 should be used. The length of *c a* (figure 31) should be eight to ten times that of *c b* in hard woods, sixteen to twenty times in the case of soft or straight grained woods.

§ 89. SCARF TO RESIST CROSS STRAINS.—When a beam is subjected to a cross stress, as for example, the tie beam of a roof truss, the indents or tables (see page 106, §85) in the upper half of the beam are compressed, while those in the lower half are subjected to a tensile stress. Consequently the indents in the upper half should be cut perpendicularly to the direction of the pressure, while those in the lower half of the beam should be made oblique. Figure 33 shows a scarfed joint constructed to resist a cross strain. The strength of the lower side depends upon

the bolts or straps. A joint subjected to a cross stress is stronger if scarfed *vertically*, as shown in figure 32.

FIG. 32.

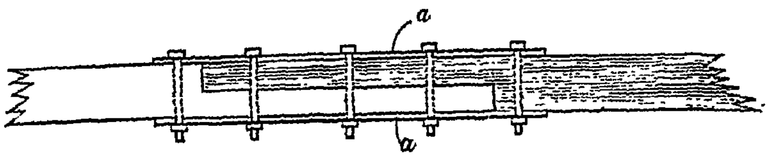


Figure 32 shows the plan of a beam scarfed vertically, and fished so as to resist a cross strain : a a *are the iron fish-plates. Scale* = $\frac{1}{20}$.

FIG. 33.

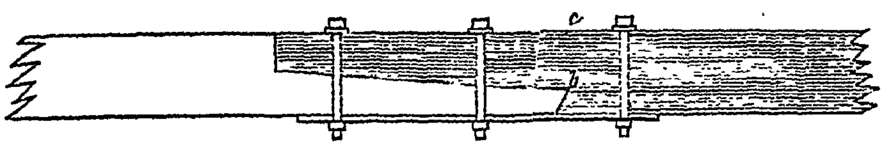


Figure 33 is the elevation of a scarfed and fished joint constructed to resist a cross strain (after Tredgold). Scale = $\frac{1}{20}$.

SCARF TO RESIST A CROSS STRAIN AND TENSION.—The scarfed joint shown in figure 33 is suited to resist both cross strains and tensions. The distance *b c* should be as great as possible in order to resist the transverse strain. A fish-plate may be added to the lower surface of the beam in order to strengthen the joint.

§ 90. TREDGOLD'S PRACTICAL RULES FOR PROPORTIONING THE DIFFERENT PARTS OF A SCARF.[1]—The total length of the scarf depends upon the kind of wood used. For tough, strong woods the grain of which is curved, such as *oak* (Quercus Robur) *and elm* (Ulmus sp. sp.) in Europe; or *Sissoo* (Dalbergia Sissoo) or *Sál* (Shorea robusta) in India, the length of the scarf should be six times the depth of the beam when no bolts are used; when soft, straight-grained woods, such as are obtained from the conifers, are joined, the length of the scarf should be twelve times the thickness of the beam. When the scarfed joint is strengthened by the addition of fish-plates its length should be three

[1] Tredgold's Elements of Carpentry, by Hurst, 4th Edition, 1883, pages 302, 303.

times the thickness of the beam for oak and hard woods, and six times that thickness for the conifers and soft woods. When indents are made in addition to fish-plates and bolts, the whole length of the scarf should be twice the depth of the beam in the case of hard woods, and four times that depth in the case of soft woods.

§ 91. Halving.—Scantlings which are supported on beams or walls are most simply lengthened by cutting away half the thickness of each beam, so that the remaining portions may exactly fit each other as is shown in figure 34.

The total thickness of the resulting joint is the same as that of the original beams. The two halved portions may be fastened by a wooden peg to prevent their drawing out.

Fig. 34.

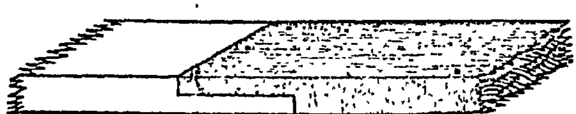


Figure 34 shows a sketch of the joint generally used in lengthening wall plates.

Figure 35 shows the usual way of joining wall plates and other beams which cross each other at an angle when there is not space to permit of the ends projecting.

Fig. 35.

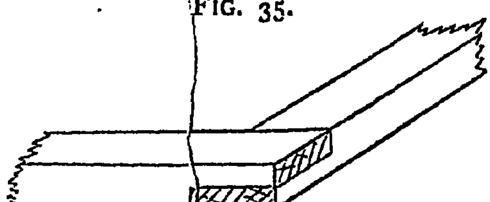


Figure 35 shows how wall plates may be joined at an angle of a building.

§ 92. Notching.—This form of joint is a modification of halving. A piece of wood is cut out of one of the beams only

when the notch is a shallow one; or out of both of the beams to be joined if the notch is a deep one, as is shown in figure 37, and the cut portions are fitted together.

FIG. 36.

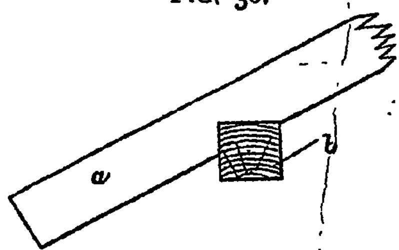


Figure 36 shows a rafter notched on to a wall plate : the rafter a *is seen in elevation, the wall plate* b *in section. Scale* = $\frac{1}{36}$.

FIG. 37.

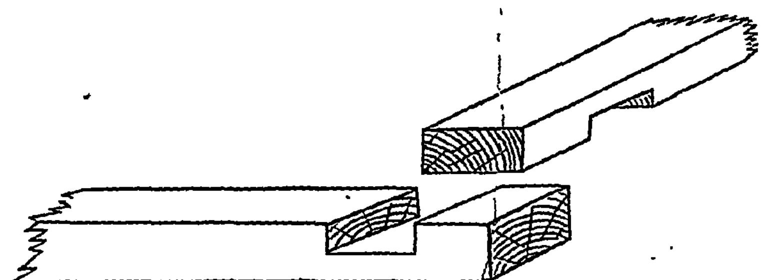


Figure 37 is a sketch to show the method of double notching two beams together.

Common rafters are notched on to the purlins which support them and to the wall-plates upon which they rest; joists supporting a floor may be notched on to the wall-plates upon which they rest and wall plates may be notched on to each other.

§ 93. COGGING.—The cog-joint is a still further modification of the notch, and is used when it is of great importance to weaken as little as possible one of the scantlings to be united together. Figure 38 shows the end of a tie beam cogged on to a wall-plate.

FIG. 38.

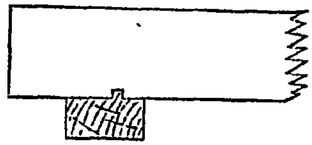


Figure 38 shows the end of a tie beam cogged on to a wall-plate: the tie beam is in elevation, the wall-plate in cross section.

The wall-plate is cut as shown in figure 38; a piece of wood, the *cog*, being left; the tie beam is cut so as to receive the cog. This form of joint is preferable to halving when the cogged beam is supported throughout its whole length.

§ 94. MORTISE AND TENON JOINT.—The common mortise and tenon joint is employed when a vertical piece of timber is to be joined to a horizontal one. The *tenon* is formed by dividing the end of the vertical beam into three equal parts cutting out the two rectangular pieces at the sides, and leaving the portion in the middle as shown in figure 39.

FIG. 39.

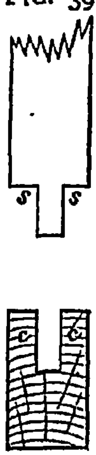


FIG. 40.

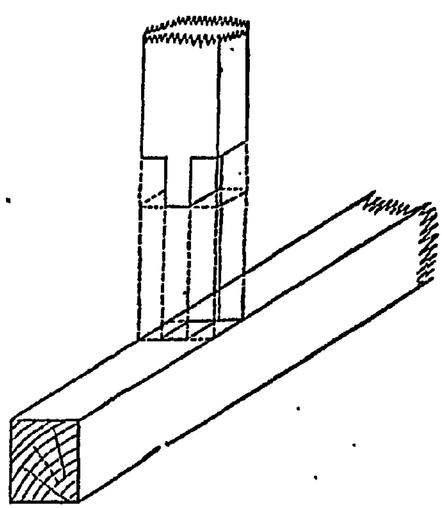


Figure 39 shows an elevation of a tenon and a section through a mortise; s s *are the shoulders of the tenon, and* c c *are the cheeks of the mortise.*

Figure 40 is a sketch of a mortise and tenon joint showing how the joint is put together.

The *mortise* is the name given to the corresponding rectangular hole cut in the horizontal beam into which the tenon fits.

In practice the tenon is made a little shorter than the mortise, so that the shoulders of the tenon may bear firmly on the upper surface of the lower beam. The sides *c c* (figure 39) are called the *cheeks* of the mortise, the portions *s s* are called the *shoulders* of the tenon.

§ 95. OBLIQUE TENON.—When scantlings are inclined together at any angle other than a right angle are joined together, the tenon has to be modified in form.

Figure 41 shows a good, strong, oblique tenon. It will be noticed that the cheeks of the mortise are cut down so as to allow the whole width of the inclined scantling to rest on the horizontal beam, in order to obtain as large a bearing surface as possible. The tenon prevents lateral motion.

The face *a b* (Fig. 41) should be perpendicular to *a c*; the length of *a b* should be a little more than half the thickness of the rafter. The thickness of the tenon should be about one-fifth of that of the rafter. The joint at *c* should be left a little open to prevent the settling of the roof causing a strain on the joint at *b*.

FIG. 41.

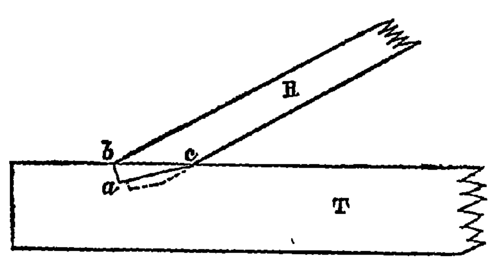


Figure 41 is the elevation of the joint between a principal rafter (R) and the tie beam (T) of a king post truss; the tenon is shown in dotted lines. Scale $=\frac{1}{20}$.

FIG. 42.

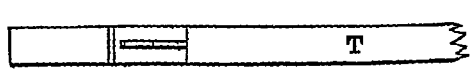
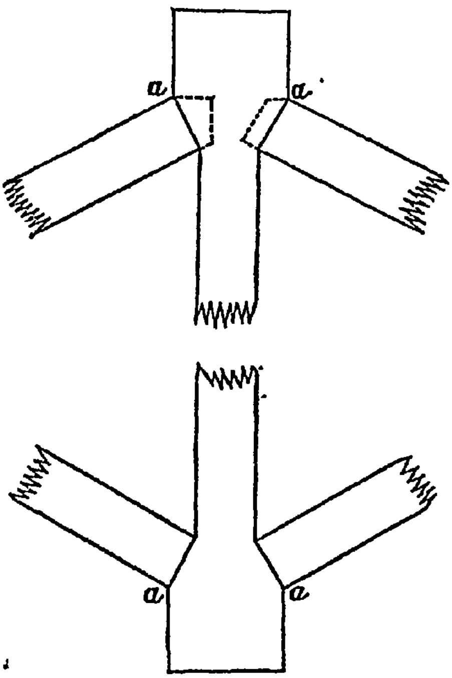


Figure 42 is the plan of the tie beam, showing the notch cut in it to receive the tenon. Scale$=\frac{1}{20}$.

This joint may be further strengthened by the addition of a strap passing round the rafter and bolted through the tie beam. This strap will counteract the shearing force which tends to cause the end of the rafter to separate from the tie beam.

FIG. 43.



An oblique mortise and tenon joint may be used to frame an inclined beam into the head or foot of a post. In this case the head or foot should be enlarged so as to form a square abutment for the inclined beam to rest on. The tenon should be made the whole depth of the inclined beam; the joints should be left a little open at *a* so as to allow for settlement. (See figure 43.)

Figure 43 is an elevation of a king post showing how the principal rafters and struts are tenoned into it. The dotted lines show the shape of the tenons (from "Notes on Building Construction"). Scale = $\frac{1}{10}$.

§ 96. MITRE JOINT.—The joint between a strut and the beam which it supports, in the case of a simple *truss* (a framed assemblage of timbers) for supporting the longitudinal beams of a bridge, may be formed by cutting the ends of the timbers which form the joint so as to exactly fit each other as shown in figure 44. Such a joint is known as a *mitre joint.*

The ends of the beams to be joined are so cut, that when brought together, the cut surfaces meet accurately, and the pressure upon every portion of the cut surfaces is equal. If the cut surfaces are only partially in contact the joint is very much weakened.

FIG. 44.

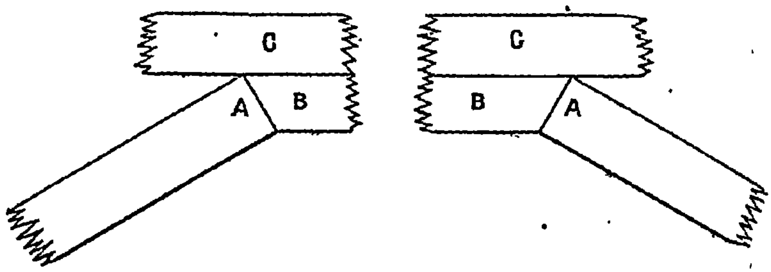


Figure 44 is the elevation of a mitre joint. A A are struts, B B the straining beam, and C C part of the longitudinal beam.

Two iron straps, placed one on either side of the beams joined, are usually added to further strengthen this kind of joint and to prevent lateral motion. The straps are bent, placed down the centres of the beams to be joined and bolted through them.

§ 97. TIE OR BRACE JOINTS.—When two scantlings inclined to each other at an angle are united, such as two rafters joined by a collar, the latter is in tension and it is very important that the joint between the end of the collar and the inclined scantlings should not draw out. In order to prevent this, a notch in the shape of a dove-tail should be cut in the rafters just deep enough to afford a bearing for the collar to rest on; the end of the collar beam should be cut so as to fit into this notch, and the two scantlings nailed or pinned together.

FIG. 45.

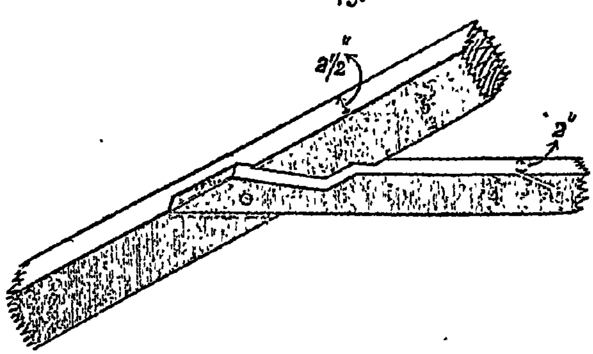


Figure 45 is a sketch of the joint between a collar beam and a rafter. The end of the collar beam is joined to the rafter by a dove-tailed notch. The joint is further strengthened by a trenail.

§ 98. SUSPENDING PIECES may be used, instead of king posts, to connect the struts and tie beam, in roof trusses; and in the construction of bridges when it is not possible to place a truss under the principal beams which carry the roadway of a bridge. Figures Nos. 46 and 47 show a front elevation and side elevation of a suspending piece to support the struts and tie beam of a king post truss.

FIG. 46.

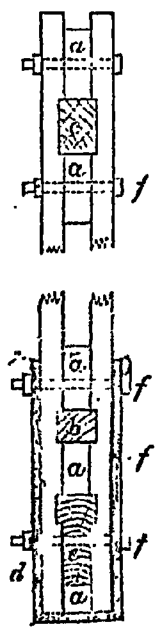


FIG. 47.

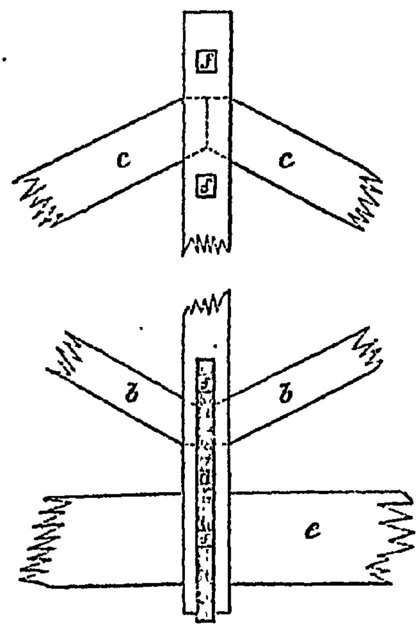


Figure 46 is a side elevation, and figure 47 a front elevation of a king post, made of two suspending pieces. a a *(figure 46) are blocks of wood,* d *is an iron stirrup fastening the suspending pieces to the tie beam;* c, c *are the principal rafters;* b, b *the braces or struts;* e *the tie beam, and* f, f *the bolts which fasten the suspending pieces together. Scale* = $\frac{1}{10}$.

The suspending pieces are best made in two thicknesses. The rafters and struts are placed abutting against each other, and the suspending pieces are notched on to them. Blocks of wood are placed between the suspending pieces, and the bolts fastening the suspending pieces together pass through them.

§ 99. SOME OF THE PHYSICAL PROPERTIES OF MATTER AND THE LOADS AND STRESSES TO WHICH THEY ARE SUBJECTED.[1]

The following short explanations of some of the more common terms employed in describing the physical properties of materials, and the stresses which may be exerted on them will be found useful.

PHYSICAL PROPERTIES OF MATTER.—*Pliability* is the tendency of a body to change its form temporarily under different stresses.

Stiffness or rigidity is the reverse of pliability, and expresses the disinclination of some bodies to change their form under stresses.

Elasticity is the property which all bodies have (in a greater or less degree of perfection) of returning to their original figure after being distorted (*i.e.*, strained) by any kind of stress. The elasticity is said to be *perfect* when the original figure is completely and quickly recovered. It is said to be *imperfect* when the original figure is not completely recovered but remains permanently distorted to a certain extent. The distortion produced is called a *permanent set* or simply a *set*.

It has been found by experiment that the elasticity of most building materials is practically perfect up to a certain point. When stresses below this point are applied and removed, the strain, distortion, or change of figure is only temporary. Stresses above this point cause *sets*. The *elastic limit* of a material is the maximum intensity of stress that can be applied to it without causing an appreciable set. This limit is however for a continued rather than a temporary stress.

A modulus of elasticity is a number representing the ratio of the intensity of stress (of any kind) to the intensity of strain (of any kind) produced by that stress, so long as the elastic limit is not passed. (*See also page 89*).

The modulus of tensile or compressive elaticity is formed by dividing the tensile or compressive stress, as the case may

[1] Notes on Building Construction, 1889, Part III, Appendix, Rivingtons, London.

be, expressed in lbs per square inch, by the respective elongation or shortening expressed as a fraction of the length of the body. In most building materials the modulus of tensile and that of compressive elasticity are practically equal to one another so long as the stresses do not exceed the elastic limit.

Deflection is the bending caused by a transverse stress : if the intensity of the stress be below the elastic limit the deflection will disappear when the stress is removed; but if the intensity of the stress be in excess of the elastic limit, a permanent *set* will remain.

Brittleness is the inclination to break suddenly under any stress.

Hardness is the property of resisting indentation or wear by friction.

Toughness is defined by Rankine as the greatest strain which a body will bear without fracture.

LOAD.—The combination of external forces acting upon a structure or part of a structure, constitutes the load which it has to support. The load may be either (1) *dead* or (2) *live*.

Dead load is that which is very gradually applied, and which remains steady. For example, the weight of the structure itself; the roofing material resting on a roof-truss.

Live load is that which is applied suddenly, or is accompanied by shocks and vibrations. A cart passing over a bridge or a sudden gust of wind acting on a structure are examples of live load. Practically a live load produces in most cases very nearly twice the *stress* and *strain* (see page 120) which a dead load of the same weight would produce.

The breaking load for any structure, part of a structure, or piece of material, is that dead load which will just produce fracture in the structure or material.

The working load is the greatest dead load which the material can with safety bear in practice.

The factor of safety is the ratio in which the breaking load exceeds the working load. This ratio varies with the nature of the load, and the nature of the material as is found by experience.

STRESSES.—*Stress* and *strain* are words which are often used indifferently either to mean the alterations of figure produced in a body by any forces, or to mean the forces producing those alterations. *Strain* has, however, recently been taken to mean the alterations of form caused by the forces, and *stress* to mean the forces producing these alterations.

Materials are subject to the undermentioned stresses which produce strains, and, when carried far enough, fractures, as stated in the accompanying table—

Stress.	*Strain.*	*Fracture.*
Tensile or Pulling.	Stretching Elongation.	Tearing.
Compressive or Thrusting.	Shortening Squeezing.	Crushing.
Transverse or Bending	Bending	Breaking across.
Shearing.	Distortion.	Cutting asunder.

Intensity of stress is the amount of stress on a given unit of surface, and is expressed in lbs or tons per square inch.

The ultimate or breaking stress on any piece of material, is the stress producing by the breaking load.

The working stress is that produced by the working load. It is always much smaller than the proof stress in order to leave a margin of safety to cover defects in material, etc.

STRENGTH.—*Tenacity or tensile strength* is the resistance offered by material to tension, that is to a stress tending to tear it asunder, as for example the tie rod of a roof.

Strength to resist crushing is the resistance offered by a material to a compressive stress, thrust, or pressure. Such a stress tends to make it shorter and eventually to crush it. Examples: a *short* column supporting a weight, a strut which keeps two walls from falling toward each other.

Shearing strength is the resistance offered by a body to being distorted by one part of it sliding on another part. Thus if two lapped iron plates united by a rivet be drawn longitudinally in opposite directions, the rivet tends to shear by the upper plate sliding upon the lower one.

Transverse strength is the resistance offered by a body to forces acting across it, tending to bend it, and eventually break it across. Thus, a beam supported at both ends and loaded over any part of its length bends downwards and tends to break across. When a body is subjected to a transverse stress, some parts of it are in compression, some in tension, and others are exposed to a shearing stress.

Strength to resist bearing is the resistance offered by a material to being indented or partially crushed by another body pressing upon it. Thus a beam may be indented by the end of a post resting on it.

The *ultimate strength* of any material is the intensity of stress required to produce fracture in any specified way.

§ 100. STRESSES TO WHICH SCANTLINGS MAY BE SUBJECTED.—The forces of *tension* and *compression* act in the direction of the length of the beam. A tensile stress has a tendency to increase the length of the beam, while a compressive stress has exactly the opposite effect.

FIG 48.

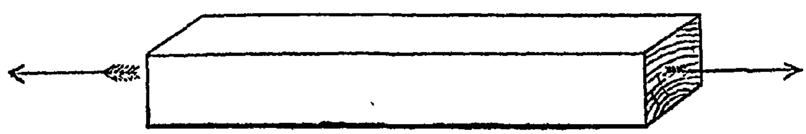


Figure 48 is a sketch of a beam in tension; the arrows indicate the direction of the tensile stresses acting on the beam.

FIG. 49.

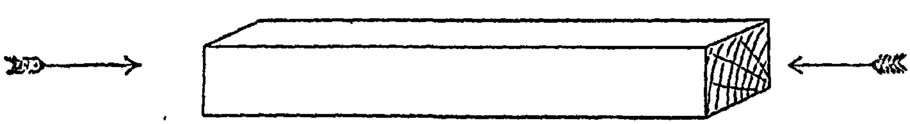


Figure 49 shows a beam in compression, the arrows indicate the direction of the compressive stress.

When a horizontal beam is at rest with these forces acting on it (see figs. 48 and 49), the two stresses are equal. If the beam is fixed at one end and pressure applied at the other in the

direction of the length, and if the equilibrium of the beam is maintained a force is generated at the fixed end called the *force of resistance*, which is at least equal and opposite to the force applied at the free end and is in many cases greater.

Pillars or posts and struts in trusses are the most common examples of the parts of a structure subjected to compression.

If W be the weight of a pillar or post and A the force attributed to the post by the weight carried by it, then the forces which act on the post are A + W in a downward direction, and B which is equal to A + W in an upward direction. B is in reality a part of the resistance of the ground (or whatever material supports the post) to compression. The total resistance offered by the ground is always considerably greater than the downward force exerted on it by the building in the case of a stable structure.

FIG. 50.

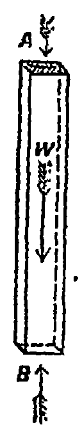


Figure 50 shows the direction of the stresses which act on a short post supporting a weight. (N. C. Macleod.)

FIG. 51.

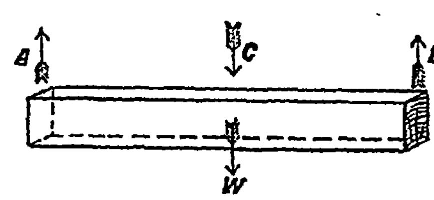


Figure 51 shows a horizontal beam subjected to a transverse stress. The two ends are supposed to be fixed, and the force C applied at right angles to the length of the beam. (N. C. Macleod.)

When there is stability, forces A and B (resistances) are generated at the two fixed ends, so that they are together

equal in magnitude to the force C and W the weight of the beam.

The force acting on the beam shown by the arrow C in figure 51 exerts a *transverse stress* on the beam.

The tie beam of a king post truss is in tension, while the wall plates supporting the rafters, which carry a roof, are subjected to a transverse strain. The tie beam of a king post truss is subject to a transverse strain as well as to a tensile force.

A beam is said to be subjected to a *shearing stress* when the effect of the forces acting on it is to tend to make it move over the beam to which it is fastened; for example, the lower ends of rafters tenoned into a tie beam have a tendency to spread abroad and move along the tie beam to which it is joined. The force which causes this motion or tendency to motion, is called a shearing force or stress.

§ 101. FASTENINGS.—In order to strengthen the joints made between scantlings, the pieces of wood which are joined together may be fastened, as has been mentioned above, by bolts or straps. In addition to these forms of fastenings the following are in general use.

Pinning is the process of inserting a pin of hard wood or iron through the timbers forming a joint, in order to prevent its different parts from separating one from the other. Pins are also sometimes added to mortise and tenon joints to prevent them from opening out.

Pieces of wood may be fastened together by means of *nails*, *spikes*, or *trenails*. Spikes are long iron nails used for fastening large scantlings together: trenails are pieces of hard wood or bamboo used like nails. They should be used in positions where iron nails would rust; they should be split out of the log, not sawn. If they are sawn, the fibres of the wood, if not quite straight, would be cut through and the strength of the trenail in consequence be considerably diminished. Trenails are usually made from $\frac{3}{8}$ths to $\frac{3}{4}$ths of an inch in diameter, and from 6 to 8 inches long. They should be made out of strong, tough wood with a fairly straight grain. In the Punjab and in North-

ern India generally very good and durable trenails are split out of the culm of the common bamboo (*Dendrocalamus strictus*) with an adze. The culm of a bamboo is particularly well suited for the purpose, as it is very hard, durable, and straight-grained, and does not shrink so much as wood in dry weather.

Screws should be used where the work may have to be taken to be pieces, or where driving in a nail might split the wood. If used in damp places, the screws should be made of copper or brass, instead of iron. Iron screws are much cheaper than either copper or brass ones.

Before the screws are placed in position a hole slightly smaller than the diameter of the screw to be used is bored in the wood, and the screw placed in position by means of a turn-screw.

Nails are much cheaper than screws, and are far more rapidly put into position; native carpenters have a great tendency to use screws where nails would do quite well, and this has to be watched.

Bolts are used either with or without fish-plates to strengthen joints. The holes made in the beams to receive the bolts weaken it to a slight extent. If the beam shrinks and the bolts are not tightened up, they give but little additional support. They can be very easily tightened up, however. The bolt itself is circular in section, and one end is formed into a solid head which is usually square and larger than the bolt proper. The other end of the bolt has a thread cut upon it and is furnished with a movable nut. The dimensions of bolts depend upon the strain which they are required to bear. The diameter of the head of the bolt and the nut is the same, and is usually one and three-quarter times that of the diameter of the bolt itself; the thickness of the head should be three-quarters of that of the diameter of the bolt, and the depth of the nut is the same as this diameter. The nut and head of the bolt are usually made either square or hexagonal in shape.

Washers are flat discs, usually of iron, used with bolts and placed between the nut and the wood to prevent the former from

injuring the wood through which the bolt passes. For conifers and soft woods generally, the diameter of the washers should be three and a half times that of the bolt; for Sâl (*Shorea robusta*) and hard woods two and half times this measurement will be sufficient. The thickness of the washers should be one-half that of the head of the bolt.

Plates may be used instead of washers to prevent the sharp corners of the nuts from injuring the timber. They considerably strengthen the joint to which they are applied. Plates are usually made of iron, but, if this is not procurable, may be constructed of well-seasoned hard wood.

Straps are often used instead of bolts in order to strengthen or form joints. They do not pass through and so weaken the beams, as bolts do. They are generally made of flat strips of iron 1½ to 2 inches broad. The thickness of the straps depends upon the quality of the iron and the strain which it has to bear; ¼ inch will be sufficient for ordinary purposes. Straps should be so fixed that the strain upon them comes in the direction of their length. The straps used to strengthen the joint between an inclined beam and a horizontal one are called *heel straps*. A strap, such as is shown in figure 46, page 117, used to fasten a tie beam to a suspending piece is called a *stirrup*. Branched straps are often used to strengthen the joints of beams meeting each other at an angle.

§ 102. DOORS.—Ordinary doors should not be made less than 2 feet 9 inches wide and 6 feet 6 inches high. The usual width for a door opening is from 3 to 3½ feet. Entrance doorways may be made of any dimensions which will suit the character of the building. If a door is more than 3½ feet wide, it should be hung in two equal portions or *leaves* as they are called; if the door is hung in two leaves, the leaves themselves are lighter and require less space when the door is open. A common way of determining the height of the door is to make it 4 feet higher than its width.

As a rule, doors should open inwards from a person entering the room, and should be placed so as to hide as much as

possible of the room when partly open. External doors are usually made to open inwards; in this case the frame of the door should be protected from the weather by a projection of the wall (see *Reveal*, page 128). External doors which open inwards should be protected by a porch or else fitted with a weather board (see page 135, § 107) projecting beyond the sill in order to prevent the rain from beating in under the door.

In exposed positions, where the rainfall is heavy, the doors should be made to open outwards, so that the *rebate* cut in the door-frame (see page 128, § 103) may prevent the rain from entering into the house. Where some of the rooms are small, the doors should be made to open outwards from the smaller rooms.

§ 103. DOOR-FRAMES.—Doors are fastened to wooden or iron frames. The frame of a door, if of wood, consists of two *posts*, *a top sill* or a *lintel* and a *bottom sill*. The upper extremities

of the posts are tenoned into the horizontal piece called the head or lintel (see figure 52), while the lower ends or *feet* are similarly fixed into the sill.

FIG. 52.

FIG. 53.

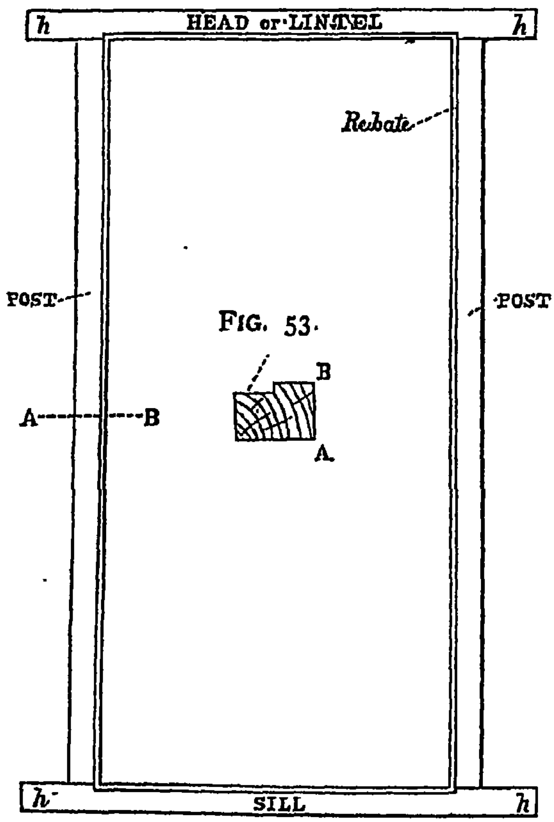


Figure 52 is an elevation of a door-frame showing the rebate and the horns (h). Scale=$\frac{1}{20}$.

Figure 53 is a cross section on A B through one of the posts of the door frame to show the rebate. Scale=$\frac{1}{10}$.

The sill should be made of hard wood or stone. A stone sill is better than a wooden one for an external door, as it is more durable. The feet of the posts may be placed in cast-iron shoes provided with a projecting spike, by means of which they can be fixed into the sill. The door-frame may be built into the masonry as the wall progresses, or it may be fastened to wooden plugs, wooden bricks, or slips built into the wall for this purpose after the walls have been completed. If the door-frame is fastened into the wall as it is being built, the ends of the lintel should be made to project beyond the posts on either side so as to form *horns;* these are included in the wall and keep the door-frame from moving. The horns of the door-frame should be tarred or painted before being placed in position. The posts and head are usually made from 4 inches by 3 inches to 4½ inches square according to the size of the door. The recesses (*reveals*) left in the external walls to receive them must be similarly proportioned. For a 3-feet door opening, the posts and head should be 4 inches by 3 inches; for a 5-feet opening, they should be 5 inches by 4 inches; while if the door-way is 7 feet wide, they should be 8 inches by 5 inches. These recesses are often omitted in India, but are very necessary for external doors in order to protect the door-posts from the weather.

A re-entering angle, the *rebate,* is made round the inside of the posts and head of the door-frame, and the door when shut fits into this angle. The rebate is shown clearly in the cross-section through the post of the door-frame in figure 53. The depth of the rebate is the same as the width of the door, while its width is usually about ½ an inch, as this is sufficient, to allow of the door fitting closely to the frame, and to prevent a draught and also to keep out rain. The portion of the wall built out into the door-opening to form the recess into which the post of the door-frame is fitted is called the *reveal.*

§ 104. KINDS OF DOORS.—The simplest kind of door is the *ledged door;* it consists of boards placed vertically, butted against each other, and connected by two or three horizontal

pieces called *ledges*. The meaning of the term butted will be apparent on reference to figure No. 54.

FIG. 54

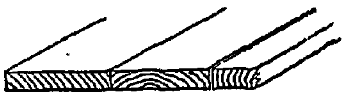


FIG. 55.

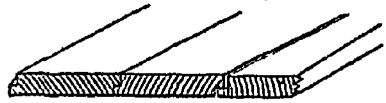


FIG. 56.

FIG. 57.

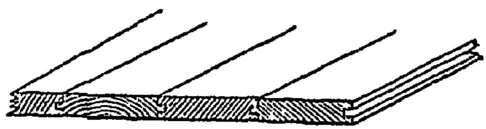


FIG. 58.

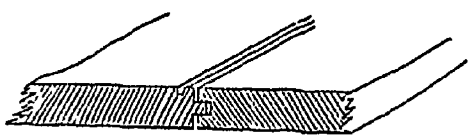


Figure 54 shows a plain butted joint. Figure 55 a rebated joint. Figure 56 a rebated, grooved, and tongued joint. Figure 57 a grooved and tongued joint. Figure 58 a beaded, tongued, and grooved joint. Scale $= \frac{1}{10}$.

Figures 54, 55 and 58 show how the joints are affected by the shrinkage of the wood. Scale$=\frac{1}{10}$. *(From notes on Building Construction.)*

The ledges should be fixed on to the inside of the door. In the better classes of ledged doors the planks may be *rebated*, or *grooved and tongued* together (see figures 56 and 57) · the joints may also be *beaded* to prevent their opening out being apparent (see figure 58). The rebate cut in the door-frame should be the same depth as the thickness of the door, if the ledges are cut so as to be the same width as the door-opening.

If the ledges are as long as the door is wide, the rebate cut in the door frame must be equal in thickness to that of the planks and ledges.

§ 105. A LEDGED AND BRACED DOOR is a ledged door which is further strengthened by the addition of diagonal pieces of wood called *braces* (see figure 59). The braces should be made to incline downwards towards the side on which the door is hung.

FIG. 59.

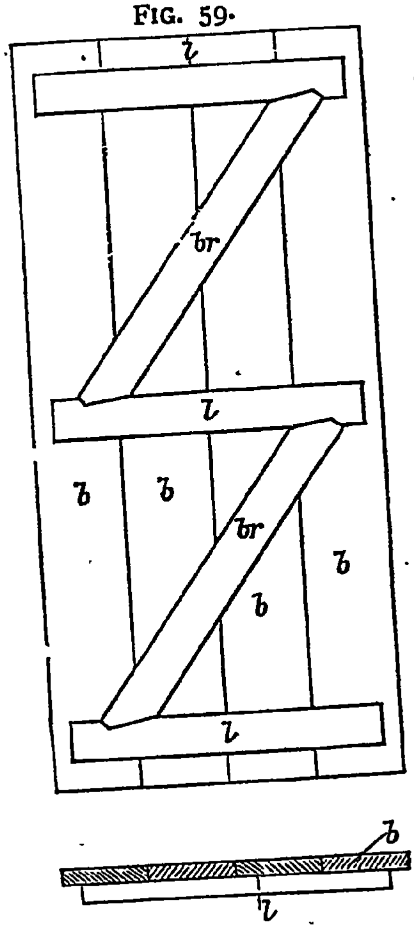


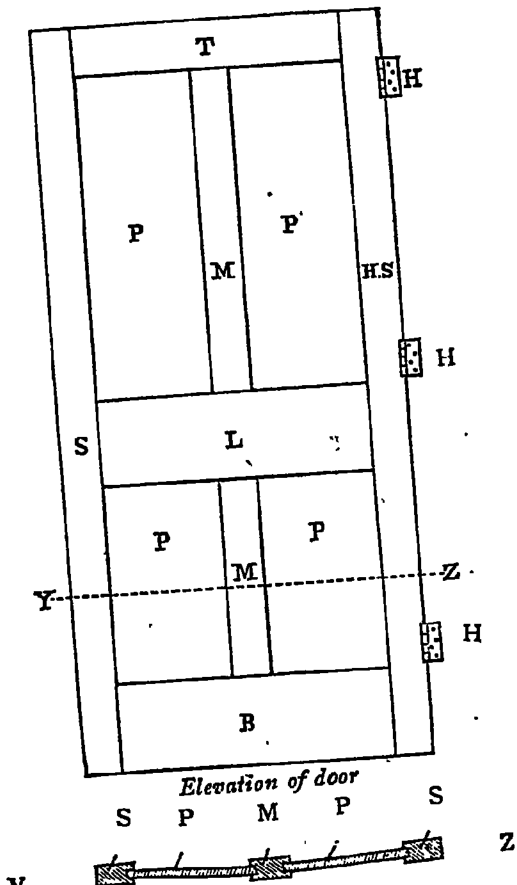
Figure 59 shows an inside elevation and plan of a ledged and braced door; b L *are boards;* br *braces;* l, l, *ledges. Scale* $= \frac{1}{20}$.

§ 106. A FRAMED AND BRACED DOOR consists of a frame in which the planks fit, strengthened by a middle or lock rail as well as diagonal braces. The ends of the braces are tenoned into the *styles* (the upright portions of the frame), and into the *rails* (the horizontal portions of the frame). The upper end of the braces should be fastened to the rails only; the lower end may be fastened into the style or the style and rail. The braces and lock rail should be thinner than the rest of the frame by the thickness of the boarding, which is nailed to them.

§ 107. A PANELLED DOOR consists of a frame-work of narrow pieces of wood of equal thickness, fastened together with mortise and tenon joints, and grooved on the inner side to receive the *panels* (see fig. 60, page 132). Ordinary panelled doors have four panels. If the upper panel is replaced by panes of glass it is called a *sashed door*.

The panels may be formed out of one piece of wood, or may consist of several narrow pieces of planking fitted in a slanting position into the door-frame. In this case the planks should be tongued, grooved, and beaded (see page 129). The advantage of the second form of panel over the plain panel is that it can be made with narrow planks. Planks 3 to 6 inches wide are commonly used for this purpose.

FIG. 60.



Elevation of door

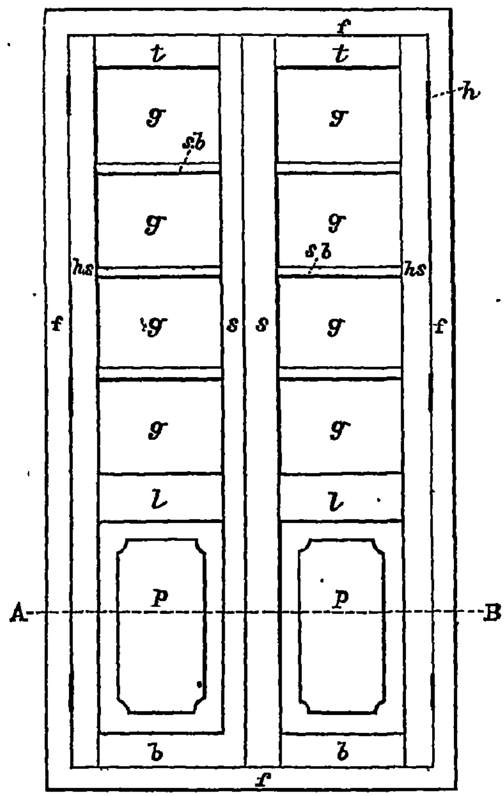
Cross Section on YZ.

Figure 60 is an elevation and cross-section of a simple panelled door: T is the top rail; L the middle or lock rail; B the bottom rail; S the style; H S the hanging style; M the munting; H, H the hinges; and P, P the panels. Scale $= \frac{1}{20}$.

The centre of the lock rail should be 2 feet 6 inches above the ground.

Figure 61 shows a sashed door in elevation and section. The names of the different parts of the doors are given in the description of the sketch.

FIG. 61.



Print.

Cross Section on AB.

Figure 61 shows the outside elevation of a two-leaved sashed door and a cross-section of the door along AB. f *is the door-frame,* b *the bottom rail,* l *the lock rail, and* t *the top rail of the door;* s *is the style,* h s *the hanging style,* p, p *the panels,* g, g *the panes of glass,* s b *the sash bars. Scale* $= \frac{1}{10}$.

In some parts of India, where it is an object to keep out the light as well as the heat during the middle of the day, at some seasons of the year, the glass portion of the door may be replaced by *venetians* (a blind made of thin battens set in a frame), or a venetian may be fixed outside the ordinary door or window, so that light can be admitted or excluded at will. The space between the styles is filled with a series of wooden battens fixed so as to slightly overlap each other when closed. An iron pin is placed in the centre of the end of each batten and fits into a hole cut in the styles of the window or door-frame to receive it. The battens are all connected centrally with a wooden rod, and by moving this rod up or down, the battens may be made to shut down on each other so as to exclude all light, or to open so as to admit light and air.

A better, though slightly more expensive method, is to have two pins attached to each end of the battens, of which the venetian is made up. The lower pins at both ends of the battens are fastened into the style of the frame in the usual way, and the upper ones fit into a separate frame which lies flat against the styles when closed. This is much stronger and neater than the old pattern of opener. (*F. A. Lodge.*)

Wooden frames, over which wire of a very fine mesh is stretched, may be fastened outside windows or in door-ways during the hot weather and rains in the plains of India, with a view to allow of free ventilation, and at the same time to keep out all kinds of insects. These wire screens should be screwed on to the window or door frames so as to allow of their being removed when not required.

The window sashes or the leaves of the doors may be removed and these screens substituted for them.

A *two-leaved* or *folding* door is one which is hung in two leaves, one leaf being fastened to either side of the opening.

In order to prevent rain water getting underneath an external door or window in an exposed position, the door step

or window sill may be *weathered*, *i.e.*, given a slight outward slope. A *weather-board* should be fastened on to the lower part of the door or window sash itself to prevent the rain from entering the room. The weather-board consists of a piece of planking nailed on near the bottom of the door, and placed in a slanting position, so that the rain beating against the door is carried off and falls beyond the sill.

When a door or window is exposed to rain, a sloping framework of wood covered with iron sheets or planks is often fastened to the wall just above the opening to prevent the rain from beating into the house.

§ 108. SLIDING DOORS.—Large and heavy doors with metal wheels attached to the top or bottom rail, may be constructed so as to run upon iron rails fixed either above or below the door. These doors open laterally.

§ 109. WINDOWS.—The size of windows is regulated to a great extent by their outward appearance and the actual requirements of the room as regards light and ventilation.

The breadth of a window should be $\frac{1}{8}$th of the sum of the width and height of the room (*Chambers*), and its height from two to two-and-half times its width. The total area of light should be equal to the square root of the cubic contents of the room (*Morris*).

Another rule for finding out the total area of light in a room is that there should be 1 square foot of window space for every 125 cubic feet of space in the room (*Galton*).

The window sill of casement windows (see § 110, page 138) should be $2\frac{1}{2}$ feet above the ground, but this is of course really a matter of choice.

If the windows do not reach nearly up to the ceiling, openings or small windows should be made near the top of the walls in order to ensure the thorough ventilation of the room. Care should, however, be taken not to place these ventilation windows on the most sunny side of the house, for that would increase the temperature of the room considerably.

A window consists of two parts: (1) the *sash* into which the panes of glass are fixed, and (2) the *frame* into which the sash itself fits. The sash is the window proper in the ordinary sense of the word. It may be fixed; hinged at the sides so as to open like a door either in one or two leaves; hung on pivots fastened near the centre of the side of the sash; or suspended by lines passing over pulleys. In the last case, the free ends of the lines are fastened to counterweights; the window-frames are hollow, and the counterweights move up and down in a vertical direction in them. In all the other cases the window-frames are solid, and a rebate is cut all around the window-frame. The sash, when closed, fits into the rebate.

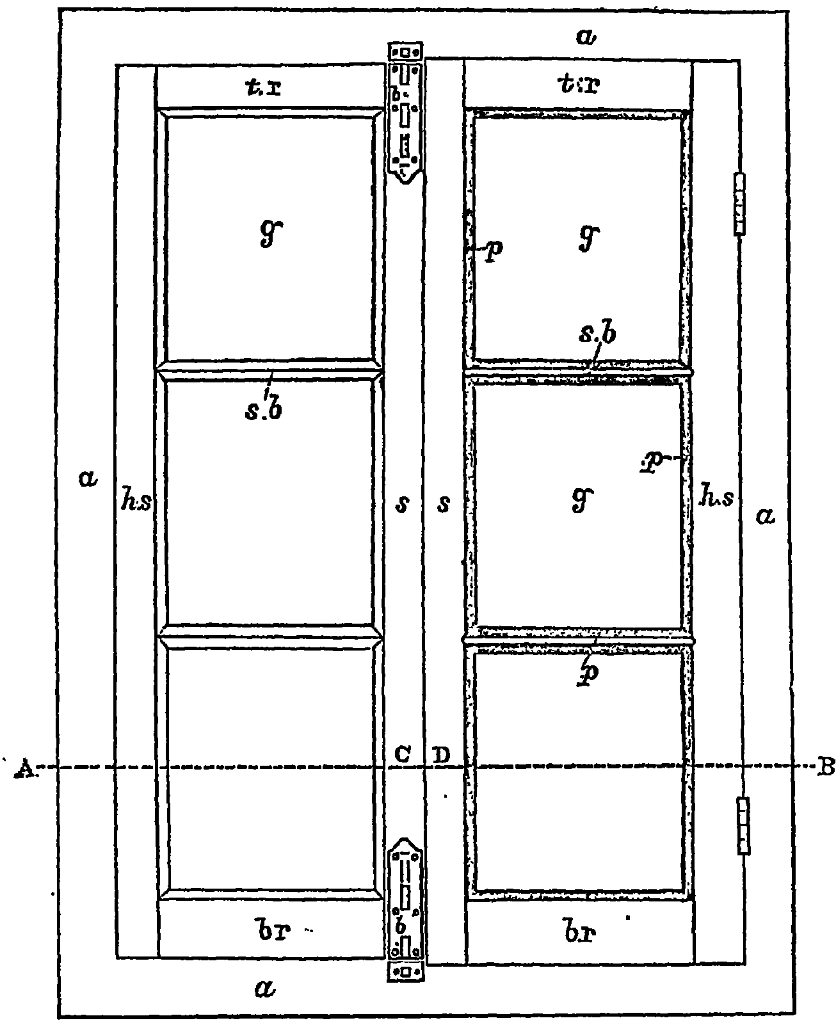
Windows should open outwards unless protected by a verandah. The rebate should be cut on the *outer* side of the frame, so that any rain water which finds its way between the sash and the window-frame may be prevented by the rebate from entering into the room: if windows are made to open outwards, there is less chance of their being blown in by the force of the wind, and there is also the convenience of being able to put things on the window sill.

The *sash* consists of rails, styles, and sash-bars tenoned together. Figure 62 shows the elevation of a simple casement window. The construction of the sash is nearly the same for all the kinds of windows in common use.

Figure 62 is a half inside, half outside elevation of a casement window with a section across the several halves of the window along AC and BD. a, a *is the window-frame;* s, s *the styles; and* h. s, h. s *the hanging styles;* s. b, s. b *the sash bars;* t. r *is the top rail, and* b. r *the bottom rail of the window sash;* g *is the glass and* p *the putty which helps to keep the glass in position;* b, b *are the bolts by which the window is kept shut. Scale* $= \frac{1}{12}$.

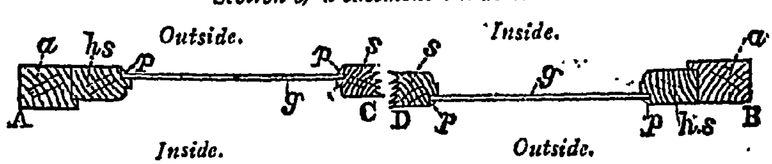
FIG. 62.

Elevation of a casement window.



Inside. *Outside.*

Section of a casement window.



In a fixed sash the vertical sash bars are tenoned into and run continuously between the top and bottom rails, and are mortised to receive the horizontal sash bars. In casement and French windows the horizontal sash bars should be continuous. The sash bars have a double rebate on the outside to receive the panes of glass. Sashes are usually made from 1½ to 2 inches thick, the rebates are about ½ an inch deep and ¼ inch wide. The styles and top rail are usually about 2 or 3 inches, and the bottom rail 3 or 4 inches wide.

In India the kinds of windows in most general use are—

(1) the casement window,
(2) the French window,
(3) the swinging window.

§ 110. CASEMENT WINDOWS are those in which the sashes are hinged vertically: they open like doors. The window-frames are solid, the rebates should be cut on the outside and the windows should, in consequence, open outwards. Casement windows are usually hung in two leaves, each leaf consisting of a frame and horizontal sash bars. In this form of window it is difficult to prevent the rain from entering where the two leaves meet; the joint between the two centre styles may be cut as shown in figure 63, and be further protected by a bead fixed to the outside of the centre style in order to keep the rain out.

FIG. 63.

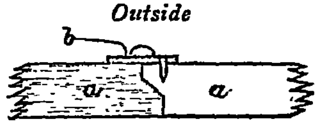


Figure 63 is a cross-section through the joint between the two centre styles of a casement window, showing the arrangement by which the rain is kept out. a, a *are the centre styles;* b *is a beaded slip of wood screwed on to the outer style. Scale* = $\frac{1}{6}$.

A weather board (see page 135, § 107) may also be fastened to the lower rail of the window sash if the rain is found to beat into the room.

§ 111. When a casement window is extended down to the floor, it is called a *French window*; such windows serve the double purpose of doors and windows, and are very generally used in India. French windows usually open out into verandahs; if they are not protected in this manner, it is difficult to keep the rain out unless a weather board is fastened to the bottom rail of the sash.

§ 112. SWINGING WINDOWS are fitted into solid frames. This form of window is well adapted for openings high up out of reach, but is not suited for large windows. The sash bars are usually made the same thickness as the frame of the window sash. For ordinary purposes 1¾ inches is a suitable thickness for the sash frame. When the windows are out of reach they can be opened and shut by means of a cord hanging down in a loop; one end of the cord should be attached to the top rail and the other to the bottom rail of the sash. Two horizontal pivots are fastened to the middle of the styles of the window sash and fit into small iron sockets let into the window-frame to receive them. The sash rotates on these pivots. The lower part of the window opens outwards. The horizontal sash bars, if any, should be continuous. The window is rendered water-tight by the addition of a bead to the upper half of the outside of the window frame. A bead is also placed on the lower half of the sash, on the outside, for the sake of appearance.

The bead (batten) on the outside of the upper half of the window-frame prevents the rain from beating in between the sash and the frame, for no rebate can be cut in the window-frame itself since the upper part of the window opens inwards. The rebate cut on the lower half of the window-frame into which the sash fits keeps the rain from entering into the room by the lower half of the window, but a beading similar to that placed on the upper half of the window-frame is added to the lower half of the sash, for appearance sake.

§ 113. GLAZING.—The operation of putting panes of glass into the sash of a window is called *glazing*. Figure 64 shows a

section through part of a sash to show the method in which the glass is fastened to the sash bars.

FIG. 64.

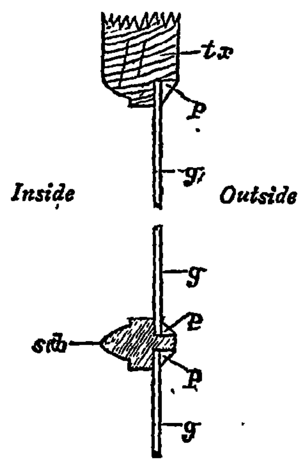


Figure 64 shows one method of glazing a window. The drawing is a vertical section through part of the sash of a window. g *is the glass,* p *the putty,* s b *the sash bar,* t r *the top rail of the sash. Scale* = $\frac{1}{4}$.

The glass is cut into the required shapes and sizes with a diamond. The dimensions of the pane should be slightly less than that of the frame into which the glass is to be fixed, so that the edges of the glass do not touch the wood-work of the sash bars anywhere. If the glass was cut so as to fit the sash very exactly the slightest expansion of the wood would cause it to crack across. A thin layer of putty (see § 80) is spread over the narrow part of the rebates, the glass pressed firmly against this and the superfluous putty squeezed out. Small brads should be added to keep the glass firmly in position while the putty is being applied. The putty is put on the face of the glass all around the edges so as to fill up the rebate. The putty should not project beyond the front of the rebate. The sash should receive one coat of paint before the glass is put in. The glass should be put in from the outside of the window, the putty being visible from the outside only. The putty should be painted to protect it from exposure to the weather.

The panes of glass in the houses in a Forest Division should be all of one size (say 12″ × 8″) so as to avoid confusion when repairs are required. (*A. G. Hobart-Hampden.*)

In Burma, panes of glass are frequently fixed into the sash by nailing thin strips of cane instead of putty. (*G. R. Long.*)

§ 114. FASTENINGS AND HINGES FOR DOORS AND WINDOWS.—In framed doors the upper hinge should be fixed on to the edge of the style just below the lower edge of the top rail, and the lowest hinge just above the level of the bottom rail, the middle one, if necessary, being placed intermediately between these two. Two hinges, one near the top and one near the bottom of the hanging style, are sufficient for light doors and windows.

Casement and French windows require fastenings to secure the sashes when shut, and also to keep them partially or wide open as may be required. A common form of fastening is a flat iron bar pivoted to the lower rail of the sash; holes are drilled in it at fixed intervals throughout its length: these may be placed on a pin fixed to the sill of the window-frame and the window kept partially or completely open by this means.

An iron rod ending in a hook, pivoted to the sill, and fitting into an eye attached to the lower rail of the sash, is often used to keep a window open, but if this be used the window can only be fixed open in one position.

Casement windows which are hung in two leaves require flush bolts at the top and foot of the style of the leaf which closes last in order to secure the window when shut.

Small slips of wood with a notch cut at one end to receive the hanging styles of the door or window are often used in India to keep them open. These slips of wood (see figure 65) are screwed on to the sill of the door or window, and can be pushed forward so as to receive the corner of the hanging style of either of the leaves of the door or window when open and thus prevent it from turning on its hinges.

FIG. 65.

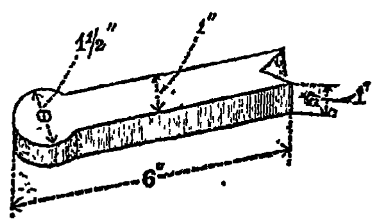


Figure 65 is a sketch of a door catch which is screwed on to the sill of the door-frame in common use in Northern India.

A small rectangular block of wood fastened by a hinge to the post of the door or window frame, half way up, is sometimes substituted for the door catch shown in fig. 65.

Handles to doors and windows are very often forgotten when houses are built, but are very necessary, and can be made locally extremely cheaply and in many ways.

G I. C. P. O.—No. 103 R. & A. D.—17-9-96.—1,000.—H. R.

Part II.—BUILDING CONSTRUCTION.

SECTION I.—FOUNDATIONS.

§ 115. The stability of a building depends primarily upon its foundations. All soils are compressed more or less by the weight of the supported building, and the amount of compression varies with the nature of the soil and that weight. Under light constructions the amount of settlement of compact soil will be unappreciable. Under heavy structures there may be some settlement, but so long as the sinking is uniform there will be no injury to the structure, though its utility may be temporarily impaired. Uniformity of settlement must be obtained by distribution of pressure and by structural precautions.

The term *foundation* has been applied both to the surface on which the lower courses of a wall are laid, and to the lower courses themselves. This procedure is apt to lead to confusion; the term *foundation* should be applied to the lower courses of masonry only, and *foundation bed* to the earth surface on which those courses are built.

§ 116. SOILS.—Foundation beds may be on rock, hard earth, compressible earth, sand, clay, peat, wet and marshy soils or quicksands. *Solid rock* of considerable thickness and not liable to decompose forms the strongest foundation. The surface of the rock should be cut away to a horizontal plane, or to a series of planes in steps, so that the foundation courses are sunk into sound rock. A heavy structure must not be built on a thin seam of rock overlying soft earth. As the dressing of a rock surface is expensive, rock foundations are seldom adopted in forest works. *Hard earth* forms a good foundation bed for ordinary buildings. In stony earth and hard clay trenches are dug just wide enough to receive the foundation of the wall, and to a depth unaffected by the weather. *Clay*

does not always furnish a good foundation bed when subjected to weather influences. It expands when wetted and contracts when dried, and is then liable to yield unequally to the pressure of the building. When exposed, clay is liable to disintegrate, and in some cases to decompose; it checks natural drainage by percolation. Clay foundations must always be well drained, and all access of surface water to the foundation bed prevented. *Compact gravel* and *sand* are practically incompressible when unable to escape either vertically or laterally. The foundation bed must therefore be deep-seated when there is any risk of escape. Lateral escape may be prevented by driving down planks or rectangular beams with edges in close contact, forming two enclosing wooden walls. No deep excavation must be made near the foundations, and any existing hole must be filled with compacted material. A sandy soil allows free percolation of rainfall and other water, and the foundation bed is kept fairly dry; still, all access of water should be prevented.

It is the experience of many that *black cotton* soil should be wholly removed over an area at least 5 feet larger each way in the horizontal plane than the actual area covered by the building. To save more expensive material the excavation may be filled with *moram*, watered and well rammed down. Moram consists of small nodules of coarse laterite mixed with fine gravel, which is found in beds more or less all over the Central Provinces and Berar. (*A. E. Lowrie.*)

Compressible and variable earths should be avoided unless special methods are adopted for making the foundation bed incompressible under its load; wet and marshy soils should, if possible, not be built upon. If a building has to be constructed on wet or marshy soil, it should be made as light as possible, and may be supported on poles (technically called *piles*) driven down into the soil until they reach a fairly stable substratum, or may be floated on a platform of sound material, such as gravel, sand, or concrete, resting on the soft ground.

For a description of piles and pile driving reference should be made to Volume II., Part IV., Bridges, Section IV., § 110 *et seq.*

§ 117. Ordinary firm earths will support a pressure of 1 ton to the square foot, softer soils ¾ ton and less. In the Punjab ¾ ton is usually taken as the pressure which ordinary soils will bear with safety.

Mr. H. Leonard, Public Works Department, states that a suitable load for the alluvial soil in Bengal is 1 ton per square foot, the depth of the foundation bed below the surface of the soil to be not less than 4 feet nor more than 6 feet, the thickness of the first or lowest course not less than 18 inches, and the narrowing of the foundation or footing courses to be at an angle of 45°.

In soft, easily compressed soil, the foundation bed may be covered with a broad layer of concrete of a thickness of 12 inches and upwards, according to the weight of the building. Such a precaution is rarely necessary in ordinary forest buildings, which are, as a rule, light, and it is generally possible to select a site where the soil is sufficiently strong to support the weight of the building.

No building should be built on *recently-made earth*, *i.e.*, newly-deposited earth. Newly-made earth will settle and consolidate for some months after deposition, unless thoroughly compacted by ramming. The time required for settling depends upon the nature of the earth of which the bank is made. A full year should be allowed in ordinary circumstances.

The construction of a building partly on solid ground and partly on made earth should always be avoided, as it is one of the most fruitful sources of the cracks which sometimes appear in the walls of a building after it has been completed and has stood for some months.

Light buildings may be placed on ground formed chiefly of blocks and fragments of stone, sufficient time being allowed for the ground to settle thoroughly before the structure is built.

If the roof is supported partly on posts and partly on walls, as is usually the case in forest buildings in the plains, the foundation beneath the verandah posts should be as strong and unyielding as that under the walls. Access of surface water to foundation beds should in all cases be prevented, and they should be well drained.

The foundations should be carried down below the reach of influences which might cause a change in the subsoil of the foundation bed. (*T. E. Ivens, P. W. D.*)

§ 118. EXCAVATION OF THE FOUNDATION BED.—Before the foundation beds are excavated, the position of the walls of the building should be all marked out by means of pegs, driven into the ground beyond the area of the excavation, and giving the angular points of the building by strings stretched from peg to peg. If the building is an important one, trial pits should be dug at intervals of 5 to 20 or 30 feet apart to ascertain the nature and depth of subsoil. The foundation bed must be in one plane, or if the ground surface is on a slope, in a series of stepped horizontal planes; on slightly uneven ground the surface may be roughly levelled, using a straight parallel-edged board and a spirit-level, or a triangular set-square frame and a plumbob; if the ground surface be more uneven, the relative height of frequent points along the site of the walls should be ascertained, so that the foundation beds may be properly stepped in horizontal planes.

The set-square frame and plumbob, mason's square (see §139, page 174), may be used for rough levelling as follows: drive firmly into the ground wooden pegs, those on the lower ground projecting to a sufficient height; apply the mason's square truly levelled to the side of a peg on the lower ground, and adjust its height till the line of sight along the lower surface of the horizontal limb cuts the next higher peg at the level of the ground. Make a mark on the peg at this exact position; the difference of level of the ground at the two pegs is the vertical distance from the mark to the ground. The pegs should be

driven in line where practicable. The battering rule figured in Volume II., Part III., Section VI., Fig. 29, page 84, can also be used.

An Abney's Level (see Volume II., Part III., page 49) can be used for ascertaining approximately differences of level, and the ordinary "dumpy" level with spirit tube mounted on the telescope tube for determining these accurately.

§ 119. FOUNDATIONS.—The foundation bed of any structure should be formed perpendicularly to the direction of, and be of sufficient area to support, the pressure due to the structure and its loading.

The area of the foundation bed is proportional to the load it has to carry. Having ascertained by direct experiment, or from a suitable example, the load per square foot which the foundation bed can safely carry, divide the total load due to the structure by the safe load, and the result is the area in square feet of the foundation bed. A cast-iron plate, or a stout timber platform, 4 feet square, may be loaded till it begins to sink into the ground, and one-fourth to one-third of this load per square foot may be taken as a safe load.

Take the lesser load when the structure is to be subjected to severe vibrations. In exceptional cases of a steady load the factor, for safety, has been raised to two-thirds, and in doubtful cases has been taken as low as one-sixth to one-eighth.

The widened area of the foundation bed is lessened, as the foundation courses are constructed, by narrowing courses called footings, and the narrowing in each course, or layer should not exceed, and is often less than, the thickness of the course. For a single course of bricks the narrowing is usually $2\frac{1}{4}$ inches, for a double course of $4\frac{1}{2}$ inches if the pressure is light, and $2\frac{1}{4}$ inches if heavy, and in like proportion for stone blocks. If there are more than three courses of brick footings, the first or lowest course must be at least two bricks thick.

FIG. 66.

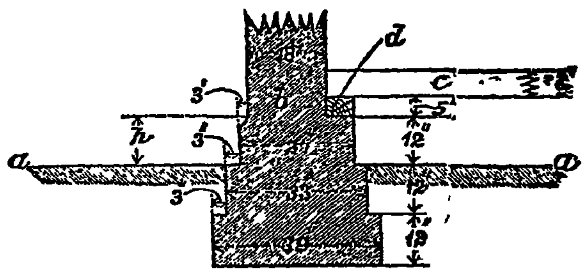


Figure 66 is a vertical section through a wall to show how the footings of the foundation are formed. a, a *shows the ground surface,* b *is the wall,* c *a floor joist,* d *the wall plate on which the floor joists rest. The height of the plinth is* p : *the outer surface of the plinth is weathered. (Scale* $= \frac{1}{36}$.)

Foundations are generally made of stone blocks or bricks set in hydraulic lime mortar, but where a large area has to be covered, or a great bulk is required, they may be constructed of hydraulic lime, or cement, concrete. The largest stones available should be used in making the foundations of a wall, more especially at the corners of the structure.

The foundations should be allowed to set perfectly hard before the walls proper are begun.

Permanent drains should be made to intercept and lead away the surface and percolating drainage, and to keep the foundations dry, unless the soil is naturally sandy. The surface of the ground should be sloped away from the building in every direction; the slope may be, if necessary, protected by an apron of concrete or brick paving.

If the building is on sloping ground, a large masonry-lined drain should be made on the up-hill side, in order to intercept the surface drainage which runs down the slopes of the hill above. Where there are no gutters attached to the eaves of the roof, this drain should be continued right around the building beneath the eaves.

When concrete is used in foundations, it should be put down in layers not more than 6 inches thick, and each layer

should be well consolidated by ramming before another is added. The narrowing of a footing course in concrete resting on clay should not be more than four-sevenths its thickness.

§ 120. PLINTH.—The narrowing of the portion of the foundation wall, which is above the surface of the ground and below the level of the ground floor, is called the *plinth*. The same term may be applied to the walling beneath the plinth course and above the footings. For this narrowing specially moulded bricks may be used, with one edge cut off or splayed so that the plinth slopes outwards and downwards (see Fig. 66, page 148), or the plinth course may be of bricks set on edge in cement, and the outer upper edge cut off to a bevelled surface.

The top course of the plinth, before the wall of the superstructure is commenced, should be brick-on-edge all over the building (if bricks are available) and under every wall. This gives better sills for the doors, and also allows of the outer edge of the plinth being bevelled. (*R. N. Hodges, P. W. D.*)

The height of the plinth varies very much. In unhealthy localities it may be necessary to make a high plinth, in order that the floors of the rooms may be raised well above the level of the ground. A high plinth adds very much to the expense of a building, as it necessitates additional construction to support the floor of the rooms, especially in the plains, where wood cannot as a rule be used on account of its liability to the attacks of white-ants and fungi, which induce decay.

In the Madras Presidency, when a plinth is required, the whole building is constructed on a series of arches, which are frequently high enough to serve as boxrooms, dog kennels, etc. The spaces between the crowns of the arches are filled in with masonry and the cross walls built upon the arches. The span of the arches does not as a rule exceed 8 feet.

In some parts of Bengal, Assam, and Burma, where range and other houses are built of wood with mat walls and a thatched roof, the wooden floor of the building should be carried on beams resting on the tops of posts firmly embedded in the ground, raising the floor the required number of feet above

the surface of the ground. Where bricks are not too costly, brick-work pillars from one to one-and-a-half bricks square should be built to carry the floor beams, and also the posts supporting the roof.

§ 121. PROTECTION AGAINST WHITE-ANTS.—White-ants (*Termes spp*) do not, as a rule, enter buildings whose walls and foundations are constructed of stones or bricks set in lime mortar. Before constructing a new building in the plains, we should be very careful to satisfy ourselves that there are no white-ants already on the area on which the building is to stand, as it is much easier to prevent white-ants from entering a building, especially one built of earth or sun-dried bricks, than expel them from a building that they have once entered. White-ants are not usually found, in large numbers, in soils which contain a large proportion of sand.

The surface of the ground of the proposed site, and for a distance of 20 feet all round, should be carefully stripped of all vegetation, so as to render any new burrows of white-ants distinctly visible; and, if any burrows are discovered, the ground should be dug up until the nest of the white-ants is reached, and this, as well as all the queen-ants that are found in it, should be destroyed. If the queen-ants are destroyed all the workers will disappear. If this operation be carefully done, there will be comparatively little chance of the ants appearing in the building after it has been erected. A continuous layer of asphalte (a mixture of mineral pitch and sand or limestone) throughout the thickness of the walls would probably effectually keep out white-ants.

Yellow arsenic (*Hartal*) has been used with great success in keeping white-ants out of buildings. The arsenic should be mixed with the concrete, mortar and plaster used in the floors, foundations and plinth of the building, as well as in the first 3 or 4 feet of the superstructure. The solution of arsenic, if used, should be confined to the foundations and the *interior* of

walls, as it is a virulent poison. The following quantities will be sufficient:—

For	concrete	4	lbs.	of arsenic	per	100	cubic feet.
„	masonry	$\frac{1}{2}$	„	do.	do.	100	do.
„	plaster	$\frac{1}{2}$	„	do.	do.	100	square feet.

The foundations and plinth of buildings constructed of mud or sun-dried bricks should be made of masonry or brickwork with a view to keeping white-ants out of the superstructure. This it does not always do, as the white-ants will sometimes construct their burrows on the outside of the masonry or brickwork, and so find their way into the wall above.

The washing over of the bed joints of three consecutive courses of the sun-dried bricks immediately above the foundations with a solution of arsenic applied with a large brush has been found to be effectual in keeping white-ants out of a building in Madras. The walls were coated with plaster (see Part I., page 48, § 38). (*F. A. Lodge.*)

An extract made by crushing the leaves of Adhatoda Vasica (*Bansa*) in the water used in mixing the mortar is said to be a preventative against white-ants. The leaves of this shrub have an exceedingly bitter taste.

§ 122. CHOICE OF SITE FOR A BUILDING.—The selection of the site of a building depends very much upon the object for which the building is to be constructed. In a town there is practically very little choice, as the building must be constructed on such ground as is available. In other cases the varying circumstances permit general rules only to be stated. The site for a building should be chosen on well-drained high ground, easily accessible to the mode of locomotion in general use in the district, and on a sandy or gravelly rather than on a clayey soil. For a dwelling-house, if it is impracticable either for physical or pecuniary reasons to bring water to the house, the site should be within reasonable distance of a good water supply; it should be centrally placed with regard to the working charge in which it is situated, and should command, if possible, a good view of the surrounding country. It is much healthier to be

exposed to winds, even hot ones, than to be sheltered from them. (*A. H. Hobart-Hampden.*)

Where extremes of heat are not experienced, eastern and southern aspects are to be preferred to northern and western ones, as they are warmer and will feel the influence of the morning sun earlier, and will be in shade in the afternoon.

Neither dense clumps of trees nor rank vegetation should be allowed to grow near a dwelling-house.

Inspection bungalows or range houses should be placed, if possible, within easy reach of—but not too near—a village where supplies are procurable. This point is of considerable importance in out-of-the-way parts of the country where supplies are difficult to obtain. (*A. W. Lushington.*)

SECTION II.—WALLS.

§ 123. Walls may be used as boundaries simply to retain earth or water; or in buildings, to support the roof and to keep out the weather. This section will be chiefly devoted to the class last mentioned.

Walls may be built of wood, brick, stone, corrugated iron, earth, grass, bamboos; and in Southern India are made of Palmyra leaves. When built of brick or stone, the blocks may be laid dry, or be cemented together with mud, lime mortar or cement mortar.

Where stone is not easily procurable, and consideration of cost precludes the use of stone, bricks, or earth, the walls of dwelling-houses and sheds are, in the moister parts of India, frequently constructed of wood or mats. In Sind, where the rainfall is very small, walls are commonly made of a wooden framework filled in with sun-dried bricks. Temporary buildings are often made of mats, sun-dried bricks, or earth until more permanent constructions can be erected.

Mat houses are constructed in Burma and parts of Bengal on account of their coolness and cheapness; and in Assam a reed, called *Ikra* (Saccharum sp.), is largely used in preference to

split bamboos for the construction of cheap or temporary houses.

§ 124. The following general remarks apply to both brick-work (bricks set in mortar) and masonry (stones set in mortar).

The walls of a building should be built up uniformly throughout the structure, and while building no part should be allowed to rise more than 3 feet above the rest.

If the walls are built to unequal heights, settlement may not be uniform and cracks may be produced in the walls. If it is necessary to build up one part of a wall in advance of the remainder, the ends of the advanced part should be built in steps to which the rest of the wall can be united when built. The steps may be one or more bricks in dimension, seldom more than three bricks.

The work should never be unduly hurried, but should be allowed to settle gradually and to set hard. Walls under construction should be kept constantly moist until the mortar has properly set. In uniting new work to old settled work, precautions must be taken against unequal settlement ; the new work must be built of full-sized bricks, sound and well shaped, and the mortar joints thin and well filled with stiff mortar paste. Portland cement or other quick-setting mortar may be used with advantage. The sides of the gap to be filled are either racked or stepped back, or if vertical are toothed, that is, left with alternate projection and recess of not less than 2¼ inches. When the new work has settled to full extent, bricks or stones may be cut out on each side of the open joint for the insertion of bonding blocks connecting the old and new work. If it is intended to add to a building at a later date, it is usual to leave stones or bricks projecting from those walls of the building which are to be added to.

In India in the cold and hot weather the air is very dry, and special precautions must be taken to prevent the abstraction of moisture from the mortar. The stones and bricks should be well soaked before they are placed in the wall and the mortar on the upper surface of the wall should be kept

well wetted. This precaution is especially necessary when the wall is long, and the workmen too few in number to build up the wall uniformly throughout its whole length. Along those portions of the wall which are not being built on it is usual to construct a little edge wall of mortar on each face of the walling, and to form at intervals cross walls (so as to divide the whole of the upper surface of the wall into a series of shallow basins), and to fill these shallow depressions with water. This precaution should be always taken at the end of each day's work in the hot weather.

Straw or reeds, stitched together in mats, is often placed along the top of a wall to prevent too rapid evaporation of the water contained in the mortar.

The upper surface of a wall should be well watered for an hour or two before new work is added.

Great attention must be paid to the through or interior bonding together of the blocks in a wall (see page 155) while it is being constructed, as after the wall is completed the through bond cannot be inspected.

§ 125. DEFINITIONS.—The following terms will be frequently made use of in the following pages :—

Headers are stones or bricks whose length lies across the thickness of a wall, the ends may appear in the face of the wall.

Stretchers are stones or bricks whose length is in or parallel to the face of the wall.

A course is a horizontal slice of a wall between two mortar joints; the depth of a course is the thickness of the bricks or stones used and one mortar joint.

The *thickness of a wall* is the distance from the face to the back of the wall; in brick-work it is expressed in terms of the length or half length of a brick, or in the corresponding inches.

Bond or *bonding* is the arrangement of bricks or stones placed together, to obtain union by overlapping, in a wall between any two bricks or stones in one course, so that the vertical joint between any other two bricks or stones in the

course, either immediately above or below it, comes over a solid block (see Figures 69–83, page 161, *et seq.*).

§ **126.** The object of breaking joint or bonding is—

(1) To distribute the pressure of the load above, so that inequalities in the load placed on the upper portion of a structure may be spread over a large and constantly increasing area of bed, in proceeding upwards or downwards, as the case may be, and

(2) To tie the wall together both lengthwise and crosswise.

In brick-work, a *header course* is a course made up entirely of headers; a *stretcher course*, one composed of stretchers only a *bat* is a broken piece of brick; a *closer* is a brick cut to size and inserted to preserve the bond or overlapping of the blocks in the wall; a *queen closer* is the longitudinal half of a brick: it is usually inserted next to the first brick at the angle of a wall.

The *face* of a squared stone or brick is its outer surface, *i.e.*, that which is exposed to view; the bottom and top *beds* are the surfaces parallel to the course in which it is laid; its *sides* are the surfaces at right angles to its bed and face; the surface in the interior of the wall parallel to the *face* is the *back*.

Quoins are the external angles or corners of buildings The term is also applied to the blocks forming the corners; these stones should, if possible, be wider and longer than those in the rest of the wall.

The *coping* is a practically weather-proof course of blocks placed on the top of a wall and preventing access of moisture to the interior. It may be built of plain burnt bricks set on edge in hydraulic mortar or in cement, or of specially moulded bricks, or of cut blocks of stone. The upper surface of the moulded bricks or stone blocks should be weathered—either loping outwards and downwards from one face of the wall, or sloping similarly from the longitudinal axis of the wall towards both faces, the angle of the slope being about 1 in 20 to 1 in 40. The coping should also be throated. The *throating* is a small

groove cut near the edge on the underside of the coping; it prevents water running off from the coping from reaching the face of the wall beneath.

The thickness of a wall may be increased by placing the bricks or stones of each course so as to project slightly beyond the course immediately below it. This process is know as *corbelling*. The projection should not exceed 2¼ inches for a single course of bricks.

A *parapet wall* is a low wall running along the edge of a roof gutter, high terrace, or bridge or road.

A *balustrade* is a similar construction, lightened by the substitution of balusters for the continuous walling.

§ 127. BRICK-WORK: PRINCIPLES OF CONSTRUCTION.—In constructing a wall of bricks set in mortar the following general principles should be carefully observed:—

1. All mis-shapen, unsound and underburnt bricks should be rejected. Vitrified bricks may be used in foundations.

2. The mortar used should be made of good lime and sand or powdered well-burnt bricks, carefully mixed with proper proportion of clean ingredients, and not more than sufficient water to allow it to be used in a stiff paste. Only freshly mixed mortar should be used. Mortar that has begun to set should not be used in any structure.

3. The beds of the courses should be perpendicular, or as nearly perpendicular as possible, to the direction of the pressure which they have to bear. In ordinary walls the beds of the courses are horizontal.

4. The bricks in each course should be made to break joint with those in the courses above and below, by overlapping to the extent of from ¼ to ½ of the length of the brick used.

5. The surface of each brick should be thoroughly cleaned and wet before it is laid in the wall. The bricks should be soaked in water for at least two or three hours previous to their being placed in the wall, and longer if practicable.

6. Every joint should be thoroughly filled with mortar; the

thickness of the mortar joints in good work should not exceed $\frac{3}{8}$ of an inch.

To prevent the joints being made too thick it is usual, in specifications (see Section XI, page 280), to prescribe a certain height which shall contain a certain number of courses of brick-work; for example, if the bricks are about $2\frac{5}{8}$ inches thick, to specify that four courses of brick shall occupy one foot in height, or that the height of four courses of brickwork, with four mortar joints, shall not exceed the height of four courses of the same bricks laid dry by more than 1 inch to $1\frac{1}{2}$ inches according to the quality of the work.

7. No pieces of bricks (*bats*) should be used to preserve the bond unless absolutely necessary to finish the end or corner of a wall, or the side of an opening. No bat used should be less than half the length of a brick.

When arches of less than 5 feet radius are built, the bricks may be cut or rubbed so that their sides are radial to the curve or to the centre of the arch. The exposed surface faces of the bricks should not be cut or dressed.

The volume of mortar required in brick-work is about $\frac{1}{3}$ of the volume of the bricks used; 1,400 bricks and 25 to 30 cubic feet of mortar should be allowed for 100 cubic feet of completed wall. The bricks alone measure 77·5 cubic feet, and 2·5 to 7·5 cubic feet of mortar is the allowance for wastage. (*R. J. Bailey, P. W. D., Lower Burma.*)

§ 128. The size of the bricks used varies in different countries and places, and according to the quality of clay and degree of burning; the usual sizes are—

In the Jabbalpore Circle . . .	$9'' \times 4\frac{1}{2}'' \times 3''$
„ Allahabad Circle. . . .	$9'' \times 4\frac{1}{2}'' \times 2\frac{1}{2}''$
At Roorkee	$12'' \times 6'' \times 2\frac{1}{2}''$
On the East Indian Railway . . .	$9'' \times 4'' \times 2\frac{1}{2}''$
The ordinary English size is . . .	$9'' \times 4\frac{1}{2}'' \times 2\frac{1}{2}''$

The length of a brick may conveniently exceed twice its breadth by the thickness of one mortar joint, so that one stretcher will occupy the same length in the wall as two headers.

Bricks are usually set in lime mortar, or, if very strong work is required, in hydraulic lime, or in cement mortar. Where lime is expensive and economy an object, or in the case of temporary buildings, bricks are sometimes laid in mud mortar. The mud used should be of tough consistency, of uniform quality, and not too sandy. The addition of chopped straw or a little cow-dung will increase the adhesive powers of mud mortar. Strict attention must be paid to the bond of such work.

Strips of hoop iron, 18 inches long, placed in the bed joints at corners of walls materially add to the strength of the structure, especially in the case of bricks set in mud mortar. Two strips are laid down along each wall of $1\frac{1}{2}$ bricks in thickness, and for thicker walls in proportion; one end of a strip is bent down 2 inches into a vertical joint, and where the other end crosses the corresponding strip the two ends are folded back to overlap. These strips may be built in the mortar joints at every 30 inches, or 10 courses, of vertical height. (*F. A. Lodge.*)

§ **129.** The systems of bond in brick-work generally used are—

(1) The English bond.

(2) The Flemish bond.

The *English bond* is considered to be the stronger of the two, and consists of laying entire courses of headers and stretchers. Headers and stretchers may be laid in alternate courses; or one course of headers may be laid to two, three, or four courses of stretchers. The stretchers tie the wall lengthwise, the headers crosswise. The relative number of courses depends upon the relative importance of strength in the longitudinal or transverse direction. One course of headers to two courses of stretchers gives equal strength in both

directions. The appearance of English bond is shown in Figure 67, the joints being represented by lines.

FIG. 67.

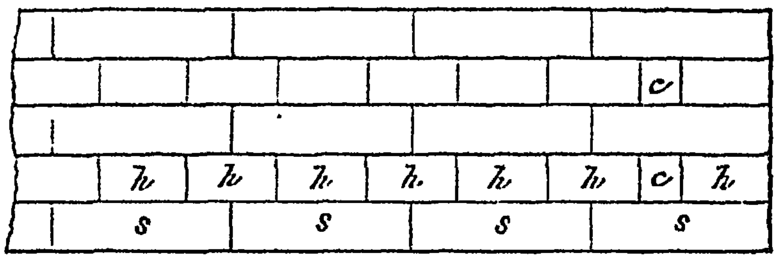


Figure 67 shows the elevation of a brick wall built in English bond. h, h *are headers,* s, s *stretchers,* c, c *closers. Scale* = $\frac{1}{10}$.

In this system there are twice as many vertical mortar joints in a course of headers as there are in a course of stretchers, and unless great care is taken to make these joints thin, two headers will occupy a little more space than one stretcher and the correct breaking of joint will be lost; *closers* are introduced to remedy this defect when the overlap becomes less than $\frac{1}{4}$ of the length of a brick.

§ 130. The *Flemish bond* consists of headers and stretchers laid alternately in the same course; the end of each header is symmetrically above the middle of a stretcher. The number of vertical joints in each course is the same, and in consequence there is less risk of losing the correct breaking of joint. Flemish bond is considered to have a neater appearance on the face than English bond, but in the case of thick walls the strength is much less, and its only advantage is its appearance.

For thin walls the Flemish bond is nearly as strong as the English bond.

Figure 68 shows the elevation of a wall built in Flemish bond.

FIG. 68.

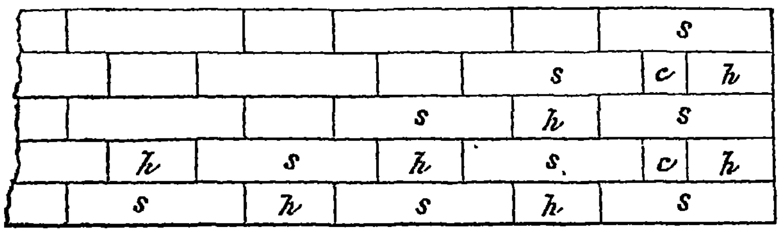


Figure 68 is the elevation of a brick wall built in Flemish bond. h, h *are headers,* s, s *stretchers,* c, c *closers. Scale* = $\frac{1}{20}$.

§ 131. Besides the above kinds of bonds the following may be mentioned:—

The Heading bond, which consists of headers only, closers being introduced where necessary to preserve the bond. This kind of bond is used chiefly for turning sharp curves, as for instance in well-linings and small culverts and arches; it has but little longitudinal strength.

§ 132. *The Stretching bond,* which consists only of stretchers, is adapted for walls half a brick thick; it is also used in chimneys to separate the flues one from another.

In *Double Flemish bond* both the front and the back of the wall are built in Flemish bond; while *Single Flemish bond* consists of Flemish bond in front and English bond at the back.

§ 133. Brick walls are built 1, 1½, 2, 2½ or 3 bricks thick, according to the weight which they have to support and the purpose for which they are built.

The following figures adapted from "Building Construction"[1] show the arrangement of the bricks in walls of the above-mentioned thicknesses built in English bond. The figures are drawn to a scale of $\frac{1}{20}$.

[1] Notes on Building Construction arranged to meet the requirements of the syllabus of the Science and Art Department of the Committee of Council on Education, South Kensington (2nd Edition, revised and enlarged), 1887. Part I, page 17, *et seq.*

FIG. 69.

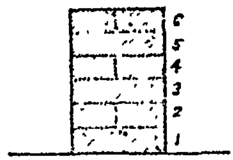


FIG. 70.

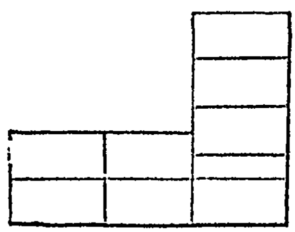


FIG. 71.

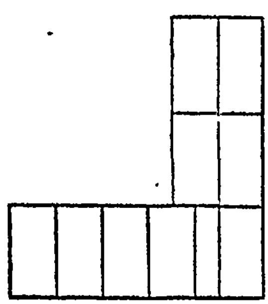


Figure 69 is a section through a wall 1 brick thick built in English bond. Scale = $\frac{1}{40}$.

Figures 70 and 71 are plans of two consecutive courses to show how the bond is preserved at the corner of the wall. Scale = $\frac{1}{30}$.

FIG. 72.

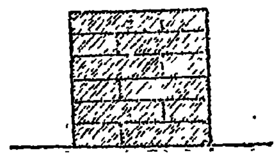


FIG. 73.

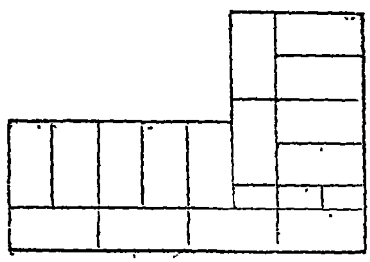


FIG. 74.

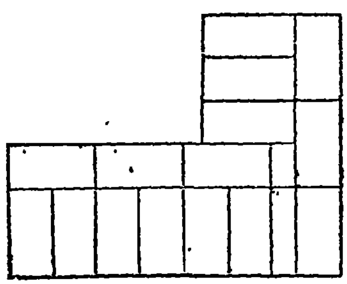


Figure 72 is a section through a wall $1\frac{1}{2}$ bricks thick built in English bond. Scale = $\frac{1}{20}$.

Figures 73 and 74 are plans of two consecutive courses of the above wall showing how the bond is preserved at the corner. Scale = $\frac{1}{20}$.

FIG. 75.

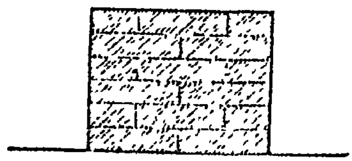


FIG. 76.

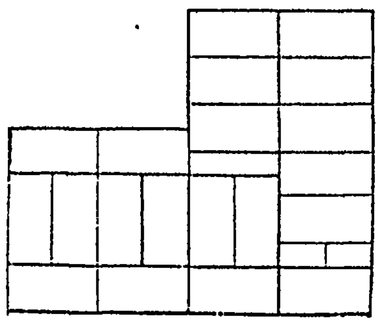


FIG. 77.

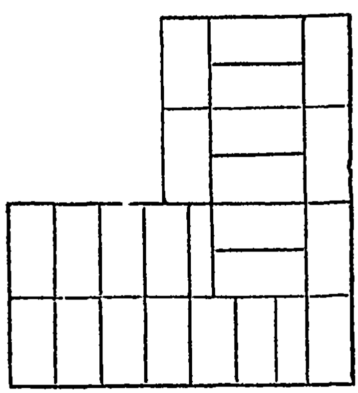


Figure 75 is a section through a wall 2 bricks thick built in English bond. Scale = $\frac{1}{16}$.

Figures 76 and 77 are plans of two consecutive courses of the above wall to show how the bond is preserved at a corner. Scale = $\frac{1}{16}$.

FIG. 78.

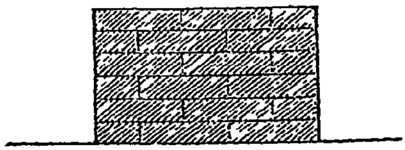


FIG. 79.

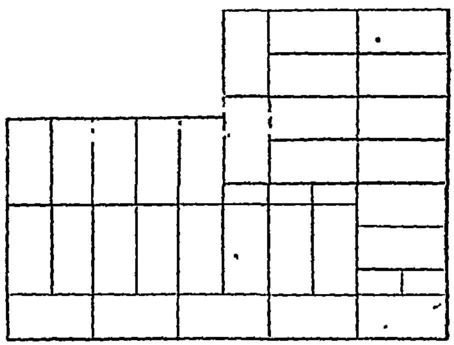


FIG. 80.

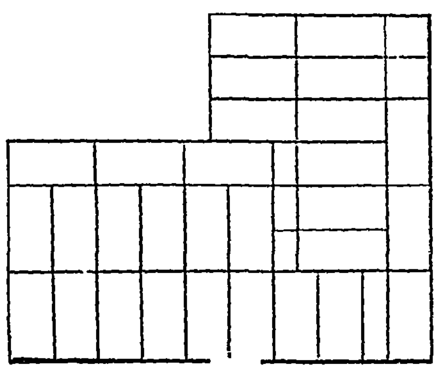


Figure 78 is a section through a wall $2\frac{1}{2}$ bricks thick built in English bond. Scale = $\frac{1}{20}$.

Figures 79 and 80 are plans of two consecutive courses of the above wall to show how the bond is preserved at a corner. Scale = $\frac{1}{20}$.

FIG. 81.

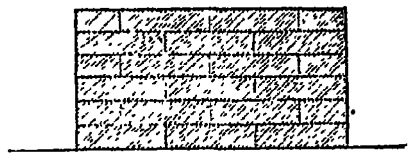


FIG. 82.

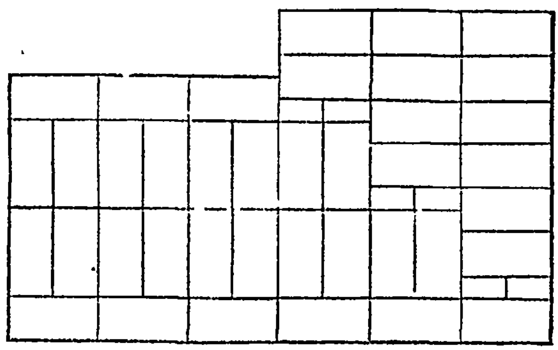


FIG. 83.

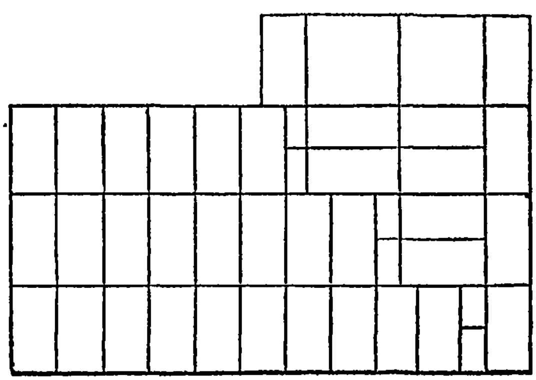


Figure 81 is a vertical section through a brick wall 3 bricks thick built in English bond. Scale = $\frac{1}{30}$.

Figures 82 and 83 are plans of two consecutive courses of the above wall to show how the bond is preserved at a corner. Scale = $\frac{1}{20}$.

§ 134. MASONRY.—In the construction of walls made of stone blocks set in mortar the following general rules should be carefully observed :—

1. The masonry should be built as far as possible in a series of courses perpendicular, or as nearly perpendicular as possible to the direction of the pressure which the wall has to bear. All continuous joints parallel to the direction of that pressure should be avoided.

2. The largest stones available should be used in the foundation courses.

3. All stratified stones should be laid on their natural bed (see Volume I, Part I, page 4) or on these inverted.

4. The construction should proceed at all points of the wall at once, no part being allowed to be built up to a greater height than the other parts; otherwise the pressure on the foundations, and consequently the settlement of the masonry, will be uneven.

5. The surfaces of all dry and porous stones should be thoroughly wetted before they are built into the wall, in order that they may not absorb from the mortar the moisture which is requisite for its setting hard.

6. Every joint and all the spaces between the stones should be thoroughly filled with mortar or with small stones completely embedded in mortar. These spaces should be kept as small as possible by carefully fitting the large stones together before placing them in the wall. The interior of a thick wall must be built solid, and not entirely of small stones.

7. If boulders are used, their surfaces must be roughened by knocking off portions of their water-worn surfaces before they are placed in the wall, and each boulder, if sufficiently large, should be broken in half. If the smooth rounded portions of the stones are not roughened, the stones will tend to slip over one another when the wall is subjected to heavy pressure. Boulders should only be used when no other kind of stone is available.

§ 135. The classification of masonry for engineering purposes is based almost entirely upon the size and shape of the stones used, and the manner in which the joints are formed.

Through headers or *bond* stones in ordinary walling should extend from face to back at regular intervals. In thick walls the header bond stones extending from each face should overlap by about 6 to 9 inches, or should overlap a heading stone built in the interior of the wall. The aggregate area of the header bond stones in the face of the walling should be from $\frac{1}{8}$ to $\frac{1}{4}$ of the total superficies. There should be strict supervision of the bonding of masonry; header bond stones should be of good length, penetrating as far as possible into the heart of the wall, and all vertical joints should be above solid stone in the course below.

Where stone is procurable, at small cost, masonry may be cheaper than brick-work, but requires greater skill in the workmen fitting the stones together, and closer supervision to ensure proper bonding. Masonry may possess less strength than brick-work, as in many cases it depends largely upon the quality of the mortar cementing the blocks together. The appearance of the face of the wall is generally of secondary importance in forest work.

The chief kinds of masonry are:—

1. *Ashlar.*—This consists of rectangular blocks of definite dimensions and built into courses of a uniform depth, usually not less than 1 foot.

Ashlar is the most expensive kind of masonry; its strength depends chiefly upon the size and quality of the stones used, the accuracy with which their faces have been dressed, the perfection of the bond, and to a less degree upon the quality of the mortar. All faces of the stones are dressed to plane surfaces. Ashlar is used mainly where ornamental work is desired, and is rarely necessary in ordinary forest constructions.

2. *Block in course.*—This differs from ashlar chiefly in that the blocks are smaller, are not dressed, plane and square over the whole of the faces, and the courses are usually from 7 to 9 inches deep, each course being of one depth throughout. The sides and beds of the blocks may be dressed plane and square for at least 4 inches back from the face of the wall, and in stronger work 8 to 12 inches back in the beds of the blocks.

3. *Rubble.*—In this kind of masonry the beds and sides of the stones are not carefully dressed, nor are the stones used accurately cut, so as to fit each other. The strength of the wall depends to a great extent upon the quality of mortar used. Considerable skill is required on the part of the masons to fit the stones together, as they vary very much in shape and size. The stones should, if possible, be laid on their widest beds, so that they may not be crushed. Headers or through bond stones should be regularly provided; the superficial area of these stones should be equal to ¼ of the surface of the wall. The headers should be arranged chequerwise, and not one over the other.

In rubble masonry the spaces between the large stones are filled in with small pieces of stone. These are usually placed in the interior of the wall; these pieces should be *as large as possible*, and should be well bedded in mortar. The interior of the wall must not be entirely made of chips. The forms of rubble masonry most commonly used are :—

(*a*) Common rubble.
(*b*) Coursed rubble.

(*a*) *Common rubble.*—In this kind of masonry the blocks are built in just as they are picked up, or as they come from the quarry, projecting portions only being knocked off with a hammer. The stones are fitted together as accurately as possible.

FIG. 84.

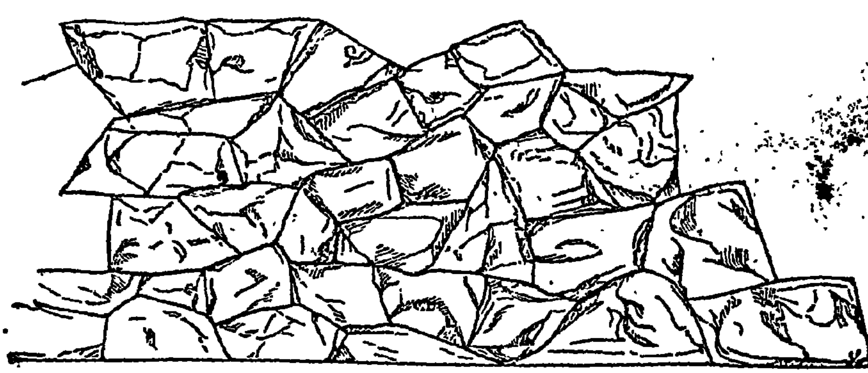
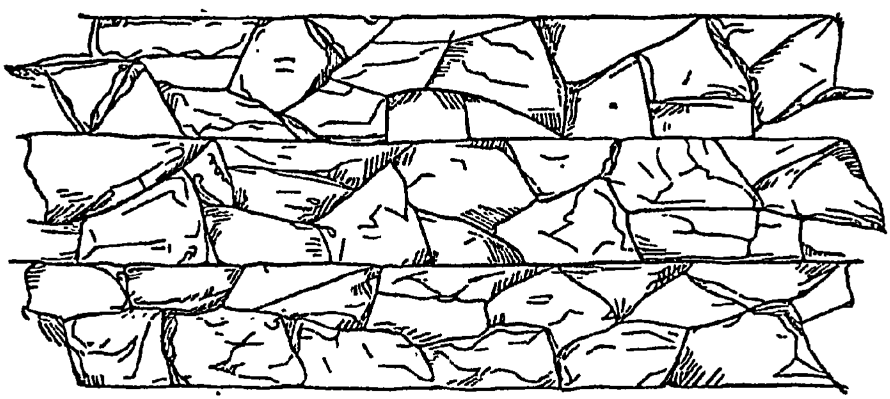


Figure 84 shows common rubble masonry in elevation.

The headers should occupy ¼ of the area of the face of the wall; the spaces between the large stones should be filled in with smaller pieces of stone and mortar. The wall is not built in courses of uniform depth. The headers of successive courses should not be vertically above each other. The stones should rest as far as possible on their natural beds, and, however small should always be made to break joint. The header stones from either face of the wall should be made to overlap as much as possible.

(*b*) *Coursed rubble* is built in a similar way to common rubble, except that the work at definite vertical intervals is built up to a horizontal or common plane.

FIG. 85.



Common rubble is sometimes strengthened by building in with it, from time to time, a course of well-bonded squared stone or two or three courses of bricks, sometimes known as a *string course.*

A combination of brick-work, or dressed stones and coursed rubble, is much stronger, and looks better than simple coursed rubble. In the better kinds of work the corners and sides of openings are constructed of bricks or dressed stones, while the intervening walling is built of common or coursed rubble

with a few string courses of bricks or dressed stones introduced at regular intervals.

In thick walls finer and closer-jointed masonry is often built on the face or faces, backed by coarser work in the interior. The facework must be well bonded to the backing by through or header stones of sufficient length and number.

§ 136. POINTING consists of scraping the mortar out from the exposed edges of the joints on the face of a wall as far as the point of the trowel can reach, and filling in the grooves thus formed with mortar made of good hydraulic lime or cement and sand. Pointing prevents the entrance of moisture in the wall and also improves its external appearance.

Walls that are to be plastered should not be pointed.

FIG. 86.

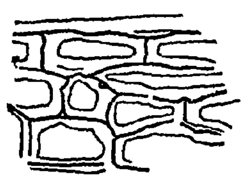


FIG. 87.

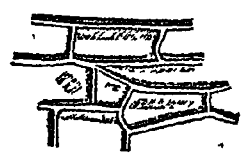


Figure 86 shows the elevation of a wall built of common rubble with the joints roughly filled in previous to pointing. Figure 87 shows the same wall after the pointing is finished.

§ 137. DRY RUBBLE is rubble masonry built without mortar or with mud. If the stones are arranged in courses, it should be called *coursed dry rubble.* Dry rubble is a very cheap form of work, but requires considerable skill on the part of the builder. The closest attention should be paid to the bond of the stones. Dry rubble is chiefly used in the construction of small dams, retaining walls, small culverts on hill roads, and in buildings or piers which are not required to support a heavy weight. The strength of a dry rubble wall depends chiefly upon the correct breaking of joint and the size of the stones used.

Where flat slabs of stone are available, strong walls or piers may be constructed of dry rubble. These can be materially strengthened by the introduction of wooden frames, at regular intervals, to enclose the stones and hold them together, as is shown in Figure 88, which is a dimensioned sketch of part of a pier of a bridge on the Bamsu sledge road, Jaunsar forest division, North-West Provinces, which was constructed in 1895, and is typical of the sledge roads in the north-west of India.

FIG. 88.

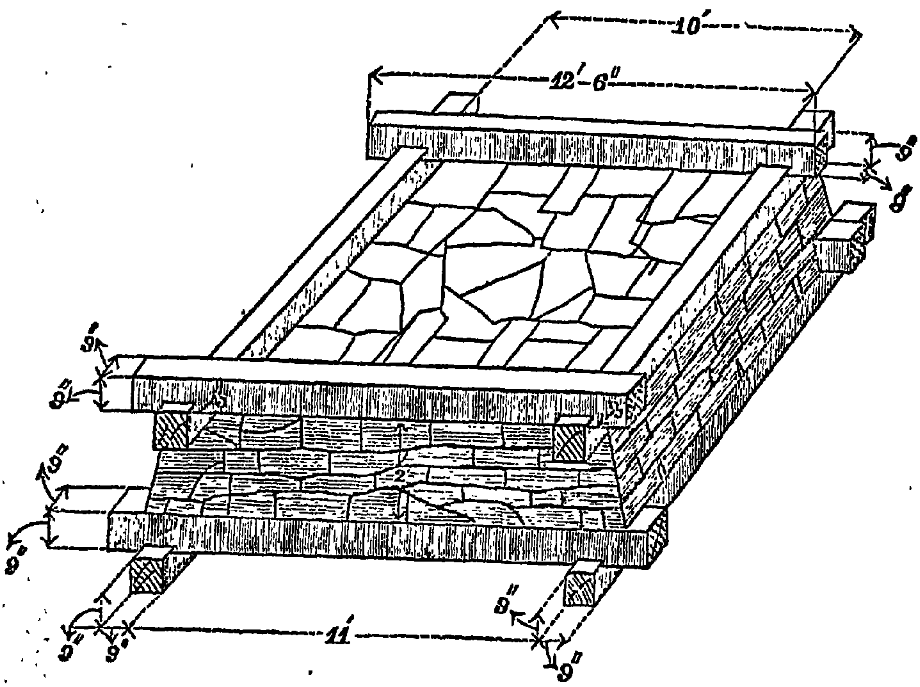


Figure 88 is a dimensioned sketch of part o af pier of a bridge on the Bamsu sledge road, showing how piers of dry rubble may be bound together by beams of wood. The wooden beams used are 9 inches square, and their lengths vary with the size of the pier. The sides of the pier are given an inclination to the vertical or batter of 1 in 4. The beams are notched about 3 inches into each other.

§ 138. EARTH WALLS may be built of earth reduced to the consistency of stiff pasty *mud.* Or the earth may be *tempered* (see page 13, § 9) and moulded into bricks, and the bricks, when sun-dried, built into the wall, set in mud mortar.

Walls constructed of stiff *mud paste* are very commonly used in India, and their construction is thoroughly understood by the natives of the country.

Lumps of the mud paste are packed together and consolidated, the upper surface of the wall is never allowed to become dry while the building is in progress; when properly constructed, the wall is a solid mass of earth. The sides of the wall always slope slightly inwards. Small stones may be left in the mud paste. When the wall is finished, the faces receive a protective coating, half an inch thick, of a mixture of clay, cow-dung, and chopped straw; an additional coating of lime plaster or whitewash is an advantage.

Mud walls must be protected from the penetration of rain water, especially at the top; an efficient coping is a layer of burnt bricks set on edge in good lime mortar. They should be carefully built in dry weather, and if efficiently protected are comparatively durable. They are, however, liable to develop cracks in a vertical direction; cracks should be filled up and the protective coating renewed as occasion requires. Mud walls will carry a light roof which must be waterproof.

Sun-dried bricks.—The bricks used are made from the best brick earth procurable near the site of the building; the earth must be well tempered, and the bricks thoroughly dried before being placed in the wall. The greatest attention is paid to proper bonding in English bond. The bricks used are uniform in size and shape, and are cemented together with stiff mud. Walls constructed of sun-dried bricks are not strong, and will not carry a heavy roof. It is very necessary to prevent water from entering into them. The top

of the walls should be protected by a course of burnt bricks on edge, laid in good lime mortar.

The faces of the walls may be covered with mud or ordinary plaster and whitewashed.

Foundations and plinth of burnt bricks, or stone blocks, set in lime mortar should be built to receive a superstructure of mud or sun-dried brick walling.

Walls made of earth are very liable to be burrowed into by white-ants.

Mud walls may be very considerably strengthened by the introduction of brick-work pillars $1\frac{1}{2}$ or 2 bricks square, or masonry pillars 2 feet square, at intervals of 5 or 6 feet. In this case the brick-work or masonry pillars should be made to support the entire weight of the roof. (*A. L. McIntyre.*)

Where lime cannot be obtained locally, the walls of small forest houses are frequently constructed of burnt bricks or stones set in mud mortar. Walls constructed in this way are stronger and more durable than if made of earth only, and will carry a heavier roof. Great care should be exercised in selecting an earth of suitable consistency for the mud mortar. (*A. G. Hobart-Hampden.*)

Where flat stones are available, fairly strong walls may be made of dry stone. The inside of the walls may be plastered, and the outside pointed for the sake of appearance if considered necessary.—(*Do.*)

In forest works, many small houses have to be constructed for temporary purposes, as inspection houses, or as guards dwelling-houses; they are built of the best materials procurable at low cost.

§ 139. INSTRUMENTS USED IN BUILDING WALLS.—The following instruments are used in building walls :—

(1) *A length of cord* for setting out straight lines, such as lines of bed-joints and the excavation for the foundation beds.

(2) A *straight edge*, a narrow piece of board, with opposite long edges perfectly straight, is used for laying out shorter straight lines and plane surfaces.

A useful straight edge, 8 to 12 feet long, can be made out of an inch plank 8 or 9 inches wide; one edge is planed perfectly straight, and the middle third of the other edge is also straight and parallel to this, the end two-thirds can be tapered off to an end depth (or width) of 4 inches.

(3) *The plumb rule and plumb line.*—The plumb rule can be made out of a plank. A line is marked down the centre of the plank parallel to one of its sides; a hole is cut in the centre of the plank near one end, and at the other end is fastened on the central line a string with a weight attached, so that the weight hangs down in the hole cut to receive it. The weighted string is known as a *plumb line* and the weight as a plumbob. When the plumb rule is held upright and the string hanging freely coincides with the line cut on the board, the parallel edge will be vertical. The plumb rule is placed against a wall from time to time in order to see that it is being carried up vertically.

(4) A *square* or *bevel plumb rule* is used for laying out vertical lines, and lines inclined to the vertical lines, the latter being used only when the thickness of the wall decreases as its height increases. The bevel plumb rule consists of three battens framed together to form a triangle; the lengths of the sides are arranged so that the hypotenuse coincides with the slope which it is required to give the wall. One of the angles of the triangle is a right angle, and one of the right angled sides is fitted with a plumbob and line, so that it can be set up vertical.

(5) A *spirit level* (carpenter's or mason's) placed on the edge of a straight edge is used for setting out horizontal lines and planes. A spirit level consists of a closed glass tube nearly filled with some spirit; it is fixed in a long rectangular block of hard wood, or in a metal case; the lower surface of the block or case is made accurately plane, and when

the block is placed on a truly horizontal surface, the bubble in the glass tube is at mid length. The upper surface of the glass tube has graduation lines cut across to indicate the accurate position of the bubble for the horizontality of the undersurface of the block.

§ 140. THE THICKNESS OF WALLS IN RELATION TO THEIR HEIGHT AND TO THE NATURE OF THE ROOFING.—The thickness of walls constructed of brick-work should be at least $\frac{1}{10}$th of their height[1] and usually from $\frac{1}{8}$th to $\frac{1}{12}$th of their height. This rule does not apply to walls made of sun-dried bricks, earth, or burnt bricks laid in mud mortar.

Long high walls carrying trussed or even flat roofs are undesirable unless cross walls or buttresses are provided.

The actual thickness of a wall in relation to its height depends very largely upon the nature of the materials used, the quality of the bond, and the weight which it has to support. Due allowance should be made for inferior materials and faulty work. For ordinary buildings, if burnt bricks are used, the outer walls need not be more than $1\frac{1}{2}$ to 2 bricks, and the foundations spreading out to 3 and 4 bricks width respectively. If stone is used, the walls should be from $1\frac{1}{2}$ to 2 feet thick, the width of the foundations being double the thickness of the wall.

In the plains of India the walls of buildings are often made thicker than is necessary, so far as their actual strength is concerned, in order to ensure greater coolness.

If the house has an upper storey, the thickness of the walls of the upper storey should be, if of brick-work, 1 brick, if of masonry, 1 foot thick.

If the roof is a heavy one (a terraced roof, for instance), the walls should be made thicker, or should be strengthened by buttresses placed at equal distances apart.

[1] Molesworth's Pocket Book of Engineering Formulæ, 21st edition, page 94.

Interior walls which do not support the roof may be made from 9 to 15 inches thick.

FIG. 89.

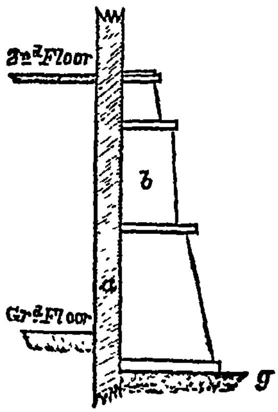


FIG. 90.

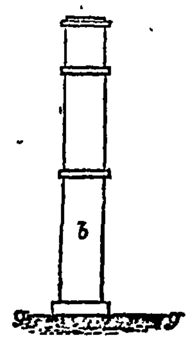


Figure 89 is the side elevation and figure 90 the front elevation of a buttress to strengthen a wall at the Imperial Forest School, Dehra Dun. a *is the wall which is strengthened, in section ;* b *is the buttress,* g *the level of the ground. The foundations of the buttress are not shown. Scale 12 feet =1 inch.* (drawn by *U. N. Kanjilal.*)

Walls of sun-dried bricks or mud, constructed to carry a light roof, should be at least 2 feet thick (at the top), and thicker if the weight of the roof is considerable. Walls constructed of dry rubble should be made of about the same thickness.

Roofs made of thatch, corrugated iron, sheet iron, or shingles can be placed with safety upon walls made of common rubble masonry, brick-work, or dry rubble ; and, if the span is small, msy be placed upon walls made of mud or sun-dried bricks; with the latter timber wall-plates (see page 177, Fig. 91) should be usod to distribute uniformly the weight of the roof.

In the case of terraced or arched roofs the walls should be

strengthened by buttresses or made thicker in order to resist the additional lateral pressure.

When a new building is to be constructed, it is always useful to take into consideration the thickness of the walls of buildings in the neighbourhood, specially of any walls built of materials similar to those intended to be used.

§ 141. WOOD BUILT INTO WALLS.—Timber should not be built into walls of masonry or brick-work, except in the case of small blocks for the attachment of the frames of doors, windows, cupboard shelves, hat pegs, panelling or pictures.

A space should be left around the ends of beams—tie-beams and joists, for example—which are built into walls, so as to allow fresh air to circulate freely around them.

FIG. 91.

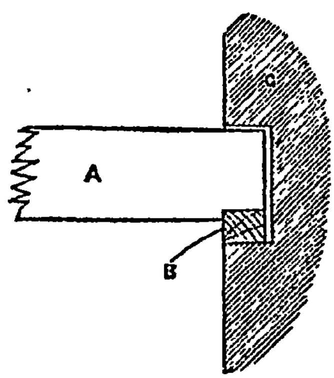


Figure 91 shows how the end of a beam should be built into a wall, a space for the free circulation of air being left. A *is the beam ;* B *is the wall-plate on to which the beam is notched ; C is part of the wall. Scale* $= \frac{1}{20}$.

Wall-plates are long beams of wood usually not less than 4 inches by 3 inches in scantling placed on the top of walls or mortised on to the tops of posts, or inserted in a space left in the face of the wall in order to distribute the weight of the floor or roof uniformly over its supports. They should be placed on, and not embedded in the walls.

Wooden lintels are wooden beams placed ac oss the top of openings in walls for doors, windows, etc. Relieving arches

(see § 145, page 183) should always be constructed over wooden lintels of greater span than 3 feet in order to carry the greater portion of the weight of the wall above; the lintel then supports only the portion of walling between the undersurface of the arch and the beam. The door or window frames are fastened to them.

Small blocks of well-seasoned wood called wood bricks, thoroughly soaked in water, may be inserted in the walls; door and window frames and other wood-work are fastened to them. They should be the same shape as the bricks used, and in thickness equal to one brick and two mortar joints. Iron hold-fasts, built into the thickness of the wall, should be used when procurable instead of wooden bricks.

Wood slips are flat pieces of wood, 9 inches long by 3 inches wide, by ⅜ of an inch thick, built into joints in masonry or brick-work, in order that the wood-work of the building may be fastened to them. They have superseded to a great extent the use of wooden bricks, as they shrink less, and when they decay leave smaller holes in the wall.

Wood plugs are used for the same purpose as wood bricks and slips; they are made cylindrical or tapered, from 4 to 6 inches long and ½ to 1 inch diameter; a hole is cut or drilled in the wall, the longer end of the plug inserted, and then embedded in good mortar paste; or the plug may be cylindrical, at one end a shallow axial saw cut is made, and a small hard wood wedge is inserted in the saw cut, the wedged end is driven home in a well-fitting hole drilled in the wall, the wedge expands the plug and ensures a good hold.

§ 142. WOOD WALLS.—Wooden walls are not suited orf houses in the plains of the drier parts of India, as they do not keep out the heat, and are not sufficiently durable; they are also rapidly destroyed by white-ants and other insects, as well as by fungi. In the hills, however, wood is frequently used for the construction of the walls of forest houses. Wooden walls are usually made of planks nailed to the timber framework which supports the roof truss. The planking may be either single or double, placed either vertically or horizontally. Seasoned wood

should be used, as green wood will shrink and change its form after it has been placed in position, and the planks will not meet properly, so that the house will be draughty and far from waterproof. If the planking is placed horizontally, it must either be made to overlap; or the planks are simply bevelled, rebated, tongued, and grooved, or joined in any of the ways shown on page 129, Figures 54 to 58.

If the planks are placed horizontally and overlapping, the lower edges should be bevelled upwards towards the house to prevent rain from creeping up the inner face (see Figure 92).

FIG. 92.

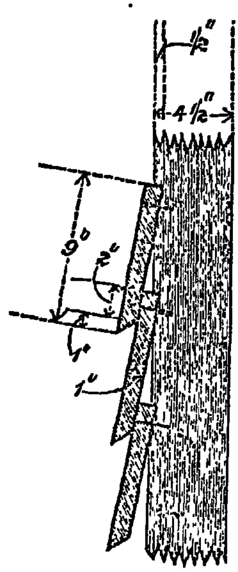


Figure 92 shows in section a method of forming a wooden wall with horizontal overlapping planks. The lower edges of the planks are bevelled so as to prevent water rising by capillarity and entering the room. The uprights to which the planks are nailed are slightly notched, so as to give the planks a flat surface to rest on. Scale = 1/12.

If the planking is arranged vertically, the planks may be joined in any of the ways shown on page 129, Figures 54 to 58. Plain 'but' joints are made watertight by nailing over the

joint a strip of wood not less than 2½ inches wide and 1 inch thick.

Except at high elevations, single planking is generally used in forest buildings, to keep the cost of the building as low as possible.

If the walls are constructed of planks nailed to the front and back of the uprights which support the roof, and the space between the planks be filled with dry grass or dry earth, the house will be much warmer and less draughty.

The planks used should be narrow, 6 to 8 inches is sufficiently wide. Narrow planks shrink and warp less than wide ones, especially when not thoroughly seasoned.

In the construction of wooden houses, the feet of the uprights which support the roof should be tenoned into wall-plates. These wall-plates, as well as the joists which support the floor boards, should rest on small stone walls made of dry rubble, or masonry, to protect them from damp and from the attacks of insects. As a rule, it will not be possible to avoid placing the main posts which carry the ridge pole in the ground, and in this case special precautions must be taken to protect them from decay and the attacks of insects (see page 70, *et seq.*). The bottom of the posts should be embedded 3 feet in the ground, unless solid rock is reached before. The posts should stand on broad flat stones, and the space around them should be packed with broken stone and sand.

§ 143. Mat Walls.—Mat walls are usually made of split bamboos interlaced so as to form a continuous surface. The mats are usually fastened on to the frame-work of the house by string. This form of wall is very cheap and cool, and is suitable for damp, moist, hot climates, but not for dry hot ones.

In Assam a reed called *ikra* (*Saccharum* sp.) is generally used for the construction of the walls of buildings. It is more lasting than either mats or split bamboos. The *ikra* is placed against or inserted in wooden battens 3 or 4 feet apart, and secured either by cane ties or wire nails. Thin split

bamboos are laid on the outside or on both sides of the *ikra* at intervals of 12 inches, and tied with cane to give stability and firmness to the walling. These walls may be plastered and whitewashed. In the case of dwelling-houses the plaster consists of lime and sand in equal proportions over a coating of cow-dung and mud plaster. (*A. L. Home.*)

SECTION III.—ARCHES.

§ 144. An *arch* is usually an arrangement of blocks in a curved beam built across a space to support a load or form a passage way. The blocks of the arch support each other partly by their shape, partly by the friction between their sides, and are also supported by the walls from which they spring.

The blocks are cut out of stone, or are cut or specially moulded bricks, ordinary rectangular bricks; or moulded blocks of concrete; arches are also constructed of concrete in one mass. The joints between the blocks should be radial to the curve of the arch at that point.

§ 145. The following are some of the terms applied to arches, and are shown in Figure 93, page 182.

The *span* of an arch is the horizontal distance from one springing line to the other.

The *rise* is the vertical height from the horizontal line joining the springings of an arch to the highest point of the soffit.

The upper surface of an arch is called the *back*, or *extrados*.

The *intrados* is the name given to its under surface.

The *soffit* is a portion of the intrados extending a short distance on each side of the keystone.

The *springing* or *spring-line* is the edge of the intrados surface from which it rises on each side of the arch.

The *skew back* is the plane or toothed surface from which the arch ring is built.

The *keystone* is the central block of the arch ring, and the *crown* is the highest portion of the arch.

The *abutments* are the masses of masonry which support a single arch, or are the end support of a series of arches.

A *pier* is the masonry pillar supporting the two adjacent feet of adjoining arches, and is consequently the intermediate

support between two arches. In a long series of arches it is advisable to build every fifth or sixth pier of extra solidity and strength, so that in case of the failure of an arch the resultant destruction may be limited to the length between two adjacent *abutment piers* and not extend throughout the whole series of arches.

The portion of masonry between the back of the arch proper and a horizontal line passing through the crown of the arches is called a *spandril.*

FIG. 93.

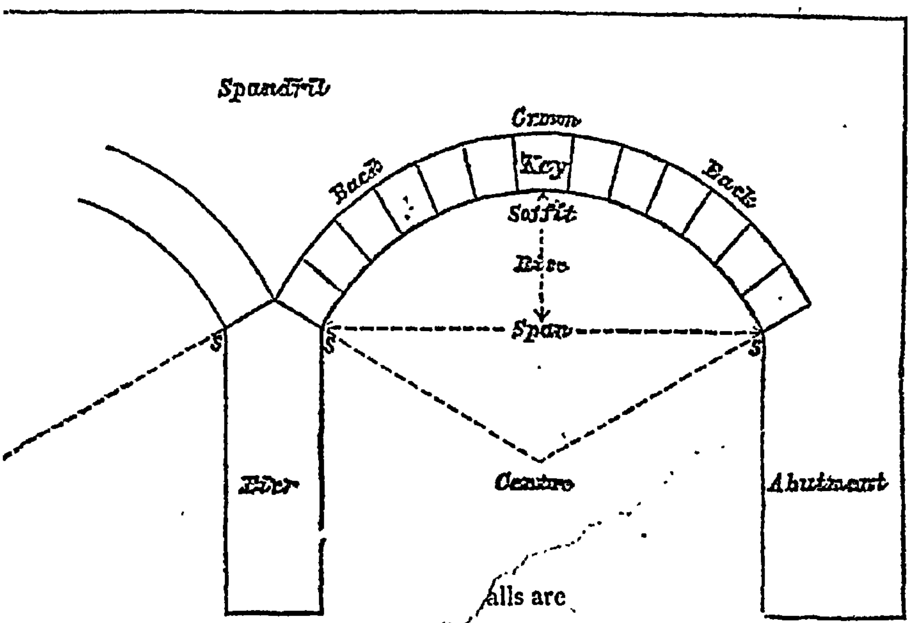


Figure 93 is the elevation of a segmental arch, showing the names given to its different parts. S, S *are the springings of the arch. (Building Construction.)*

The *inverted arch* or *invert* is built with the intrados uppermost and is generally used to connect together adjacent piers and abutments, distributing the load due to the structure, etc., over the whole area covered by it; also strutting apart the piers, etc., at their feet; and also furnishing a solid durable

flooring to a waterway. The rise of an inverted arch is generally about one-fifth of its span.

Relieving arches are built over stone or lintel beams, in order to carry the major part of the weight of walling above, thus relieving the lintel of all load except that due to the small portion of walling beneath the arch. They are either semi-circular or segmental arch rings. The relieving arch must spring clear of, and not rest upon, the ends of the lintel beam or of the straight arch; and when the lateral thrust of the relieving arch is of importance, either strong buttresses must be built or the lateral thrust must be counteracted by a strong wrought-iron tie rod, bracing together the feet of the arch ring or its supports. This case often occurs with segmental relieving arches over wide doorways near the corner of a building or over a doorway occupying the greater part of the width of a gable end of a building; and the ordinary walling does not furnish sufficient resistance to the arch. The core or brick-work filling the space between the relieving arch and the lintel must not be built to carry any part of the arch ring.

§ 146. The most common forms of arches are—

(1) The semi-circular.
(2) The segmental.
(3) Three or more centred arch ring.
(4) The elliptical.

The elliptical arch is not as strong as the segmental, but is considered to have a more graceful curve, and also to afford a larger area of waterway for a flooded stream. The direction of the thrust of a semi-circular or elliptical arch is mainly vertically downwards, that of a segmental arch is at right angles to the radial surface from which it springs.

Section of the intrados of a *semi-circular* arch is a semi-circle, while that of a *segmental* arch is an arc of a circle less than a semi-circle. In (3) and (4) the curve of the arch ring is struck from 3 to 7 centres. The so-called straight arch is a beam of brick-work made of bricks cut and sometimes rubbed smooth to shape; the joints are radial to a centre found at the

apex of an equilateral triangle based on the span *a b* (see Figure 94).

If *a b* intrados of a straight arch is built with a slight rise to the centre, the arch is said to be *cambered.* The amount of the rise or camber varies from $\frac{1}{6}$ to $\frac{1}{8}$ inch per foot in the half span; the back or extrados of the arch is given half the camber given to the soffit. The object of giving an arch a camber is to ensure that, after the settlement of the arch has taken place, the intrados shall be either horizontal or slightly curved upwards.

FIG. 94.

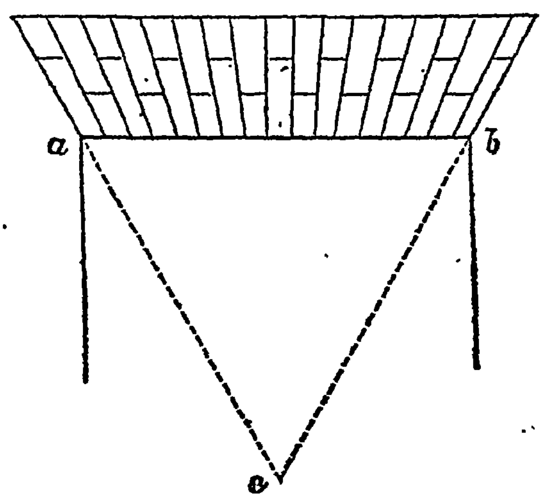


Figure 94 is the elevation of straight arch in brick-work, one and a half bricks thick, showing the method of construction.

§ 147. BRICK ARCHES.—In *plain, common,* or *rough brick* arches ordinary rectangular bricks are used. These parallel-sided bricks are placed radial to the curve of the arch, and the joints are wider at the extrados of the arch ring than at the intrados. In arches of small radius (say, 3 to 4 feet) the bricks should be placed as stretchers in the intrados surface, making an arch ring of half a brick ($4\frac{1}{2}$ inches) in depth. In arches of larger radius the bricks may be placed as headers to the intrados without making an unduly wide joint in the extrados;

but a common practice is to build instead two or more half brick concentric arch rings, an ordinary road bridge over a railway being built with 5 half brick arch rings over a span of about 26 feet, for a segmental arch having a rise of one-fourth to one-fifth of the span. Plain arches are used in road culverts and bridges and similar works, also in relieving arches over door and window openings, where the work is either hidden or its appearance is unimportant.

FIG. 95.

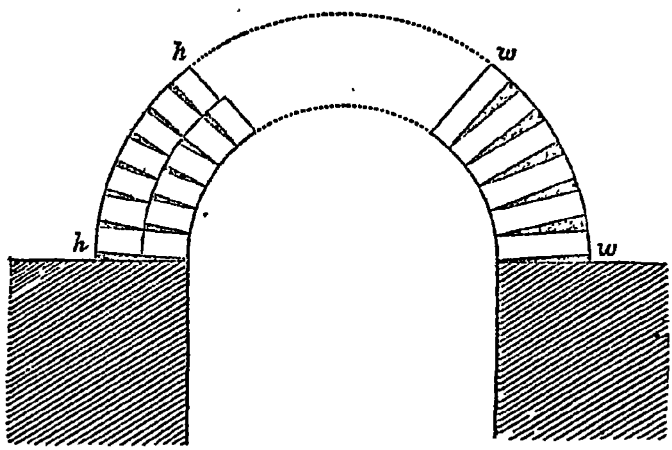


Figure 95 shows the elevation of a rough brick arch turned in rings half a brick (h, h), *and one brick* (w, w) *thick. The shaded portions of the arch are mortar joints. Scale* = $\frac{1}{20}$. (*Building Construction.*)

Rough cut or *axed* arches are made of bricks roughly cut with a bricklayer's axe to the shape of a wedge; they are used over openings, when the work is to be plastered, in relieving arches and in inferior work.

Gauged arches are built with bricks accurately cut and rubbed so that their sides fit together closely, and are radial to the curve of the arch. They are used chiefly in external arches over openings and recesses in superior work, and are often made of bricks which are larger and softer than those used in the construction of walls.

Openings in external walls of houses may have a gauged arch ring 4½ inches thick built in the face for the sake of appearance, it covers a relieving arch supporting the main part of the walling.

§ 148. STONE ARCHES may be constructed of large stones accurately cut into wedge-shaped blocks (*cut stone arches*) or of small stones roughly dressed to a wedge shape (*rubble arches*). In the former case the size of each block should be actually found by laying out the arch on a board, if small; or if large, by drawing the arch to scale, fixing the number of stones to be used and the depth of the arch, and then graphically determining the exact size and shape of the stones. In setting out an important arch, the space to be occupied by each stone, or brick, and the mortar joints should be marked off on the *centre* (see § 150) before the arch is begun. The arch should be built up in even courses from either skewback towards the crown, the key-stone and course which forms the actual crown of the rach being carefully fitted and driven gently into its place last of all. If the arching is of considerable width, as in a bridge, the stones or bricks of which it is built must break joint properly in the successive courses.

Rubble arches are made of smaller stones roughly cut into a wedge shape; they should be laid in good mortar, as their strength depends to a great extent upon its cementing properties.

§ 149. In the practical construction of arches in connection with forest works where skilled labour is not available, it is often necessary to take special precautions to see that the joints of the arches are correctly constructed. We must see that the joints radiate correctly from the centre or centres from which the arch is constructed. This may be done by driving a nail into the centring at the geometrical centre of the arch, and a string stretched from this to the arch which is being made should be a sufficient guide to ensure the joints being truly set. A line of nails placed round the curve of the centring, at the places where the joints between the bricks or stones should fall, will ensure that the right number of stones or bricks shall be used. (*A. G. Hobart-Hampden.*)

§ 150. The CENTRE is the frame-work which supports the stones or bricks of which the arch is composed while they are

being placed in position, and until the whole structure is complete. A *centre* or *centring*, as the construction is sometimes called, may consist of a frame-work of timber or of iron, or be built up solidly of bricks; in the latter case the upper sides of the bricks are faced with mud or mortar in order to obtain the shape required for the soffit of the arch.

The centre must be sufficiently strong to bear the weight of the arch while it is being built, and also be easy to remove when the arch is finished.

Figure 96 is the elevation of a wooden centre, showing the arch in process of construction.

FIG. 96.

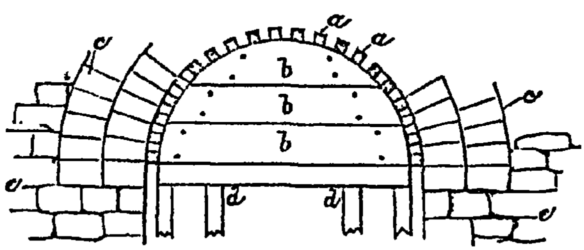


Figure 96 is the elevation of a wooden centre for a semi-circular arch. a, a *are the battens (seen in cross section) which support the bricks while the arch is being constructed;* b, b *boards forming the ends of the centring;* d, d *the posts which keep it in position;* c, c *the bricks forming the arch;* e, e *the wall in which the arch is constructed.*

A common Indian method of forming a centre is to build up a number of pillars of burnt bricks set in mud and connected at the top with strong rough poles or beams: brick-work set in mud, or else smaller poles are laid on the top of the rough timber, in order to obtain roughly the required shape of the arch; the exact curve of the arch is obtained by plastering the centre with a mixture of surkhí and cow-dung. The curve required is gauged by properly constructed wooden frames introduced into the centring at intervals. Small holes are left in the centring to allow rain and other superfluous water to run off. This method of constructing the centring is cheap, as the bricks used in its construction can afterwards be utilized in making the floors.

The centring of small arches is lowered and is removed by slackening the long hard wood wedges which have been driven in pairs in opposite directions under each centre frame. For mud-covered centres the dry mud is gradually raked out beneath the arch ring; but in the case of large ones the centring should be slowly lowered bodily, in order to ensure uniform settling of the arch. The simplest way to effect this is to allow the lower ends of the posts (d, d Fig. 96) to rest on planks which fit easily inside boxes (old packing cases bound with strips of iron will do) filled with sand. The boxes rest on the ground, and one or two holes are bored in their sides low down; these holes are filled with plugs. When the centring is to be lowered, one or more plugs are removed from each box, the sand in the boxes is thus allowed to escape, and the centring sinks uniformly and slowly. The centring can be made to sink uniformly and slowly by regulating the flow of sand from the different boxes by replacing or withdrawing plugs as may be necessary. (*F. A. Lodge.*)

SECTION IV.—FLOORS.

§ 151. Floors may be constructed of tiles, bricks set on edge, slabs of stone, or of bricks or tiles covered with a layer of concrete, mortar, or cement. They are sometimes made of concrete alone. Floors constructed of concrete, or broken stone and cement or mortar, are known as *terraced floors*. In the hills floors are usually made of wood. The floors of rooms on the second storey of houses, generally, are often made of wood on account of its lightness. Wood is rarely used for the ground floors of permanent buildings in the plains on account of the initial cost of suitable wood and the damage which may be done to it by insects, especially white-ants. A great number of the houses in the plains of India have only one storey; in consequence the weight of floor need not be considered, and they are usually constructed of some material more durable than wood. Houses which have wooden or mat walls should also have wooden floors as there is no object in constructing a floor which would be more durable than the other parts of the

building. The floor is, in such cases, generally placed at some height above the ground.

§ 152. BRICK-ON-EDGE FLOORS.—The ground should first be very carefully levelled, or made the shape which the floor is ultimately to have, before any of the bricks are placed in position. If necessary the ground should be thoroughly consolidated by ramming. A layer of dry sand, 3 inches deep, placed on the surface of the ground, is a good preventive against damp and white-ants. The distance of the top of the layer of sand below the surface of the finished floor varies with the size of the bricks and the number of courses laid, as will be seen on examination of Figure 97. One or two courses of bricks are laid flat, and set in mortar, leaving room for the upper brick-on-edge course. Only the best-shaped and thoroughly burnt bricks should be used for the top course; the faces which are to be placed in contact should be rubbed until they are perfectly smooth, so that they may be laid quite close to each other with a thin joint of cement or mortar between them. The side of the brick last laid should be covered with mortar before the next brick is placed in position. If the bricks in the top course are laid in rows diagonally across the floor, the floor will last longer. If the floor is not subjected to heavy wear, one row of flat bricks will form a sufficiently strong foundation for the brick-on-edge course.

The layer of sand referred to above is frequently omittedin order to save expense.

FIG. 97.

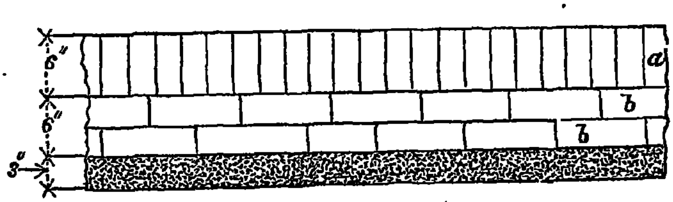


Figure 97 is a vertical section through a brick-on-edge floor. a *is the top course of bricks set on edge;* b, b *are the two courses of bricks laid flat;* c *is a layer of sand. The mortar joints have not been shown separately. Scale* $= \frac{1}{20}$.

§ 153. Tiled Floors.—Square tiles of from 15 to 18 inches side, and 2 to 2½ inches thick, are well suited for the construction of a floor. The tiles must be correctly squared, and their edges should be trimmed so that the joints between them may be as fine as possible. The tiles may be laid on a foundation of concrete or of bricks set in mortar, if an especially strong floor is required; or may be simply placed on the top of a 3-inch layer of sand or on the surface of the earth if the floor is not required to support a heavy weight. The area on which the floor is laid must be carefully levelled before the actual floor is constructed.

§ 154. Stone Floors.—When flag-stones are procurable they are in many cases preferable to tiles, as they are more durable and less liable to injury. Stones which absorb or retain moisture should not be used. A 3-inch layer of concrete consolidated to 2½ inches is usually first spread over the bed of the floor, and when this has set, the flag-stones, which should be carefully dressed, are laid in position.

The mortar joints between the flags should not be more than $\frac{1}{16}$th of an inch thick. The flags should be kept watered for a week at least after they have been laid, so as to ensure the mortar setting properly.

Where regular flag-stones cannot be obtained, a serviceable floor may sometimes be made of stones, which are easily fissile and when split present a fairly flat surface. The sides of the stones should be roughly squared, and the stones should be cut so as to fit each other and to allow of thin mortar joints being made. The joints should be pointed with good lime, or if procurable cement mortar. The stones should, as far as possible, be of a uniform thickness of not less than 2 inches. They may be laid on the ground surface after it has been thoroughly rammed, or on a 3-inch layer of well consolidated broken stone.

§ 155. Terraced Floors.—The durability of a terraced floor depends chiefly upon the quality of the mortar used and the care with which the concrete and mortar are consolidated.

The ground is first prepared as described in the case of a brick-on-edge floor, and a layer of sand (if such be used) carefully laid. Then a 4-inch layer of fine concrete is placed over the layer of sand (which should be well watered), thoroughly moistened, and beaten with light wooden hand-mallets (*thápis*) until the mortar has set; the thickness of the layer of concrete when the process of consolidation is complete should be three inches. During the process of consolidation a large proportion of the lime and finer particles will work their way to the surface. The surface should be rubbed smooth, and before quite dry can be enamelled with fine lime plaster about ½ an inch thick, and if necessary polished with a trowel. If this layer of plaster is made with surkhí (§ 30, page 43) instead of sand, the resulting colour of the floor will be dark red instead of white.

Floors of this description will be sufficiently strong and durable for dwelling-houses. Verandah floors thus constructed should be given an outward slope of 1 in 40, and the floor of the verandah itself should be made an inch or two lower than those of the rooms of the house.

The different days' work must be carefully joined; no part of the work must be allowed to dry from the time it is first laid until it is quite finished. The surface of the work may be kept moist by covering it with a layer of damp sand or straw, which should be watered from time to time as it dries.

The commencement of the cold weather is the best time for this work.

A terraced floor may, where great strength is required, be constructed by first putting down a course of bricks laid flat on the top of a 3-inch layer of sand, and placing on this a 4-inch layer of concrete, which should be consolidated by ramming to 3 inches.

A layer of plaster about ½ an inch thick should be placed on the top of the concrete and worked to a smooth surface.

Figure 98 shows a section through a terraced floor, laid on bricks, and resting on a layer of sand.

FIG. 98.

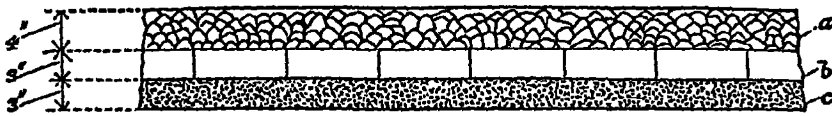


Figure 98 is a cross section through a terraced floor. a *is a layer of Concrete 4 inches thick, the upper surface of which is polished;* b *is a layer of bricks laid flat, set in mortar, the depth of this course being 3 inches;* c *is a layer of sand 3 inches deep. Scale* $= \frac{1}{20}$.

The following gives a clean, good floor well adapted for forest rest-houses, it also helps to keep white-ants from coming through the floor. After the surface of the ground has been levelled, 3 inches of broken stone or brick are laid on it, well watered and rammed. Over this 1½ inches of good, clean sand is evenly spread. On this being completed ordinary coal-tar is sprinkled lightly over the entire area, and over this again fine sand is sifted through a basket. Two gallons of tar will be sufficient for 100 square feet of floor surface. The whole surface is then well rammed with ordinary wooden rammers. The success of the floor depends upon the ramming, for, as the ramming continues, the tar keeps rising to the surface. As this appears, fine sand must be sifted on, until eventually the whole is one consolidated firm mass. (*A. E. Lowrie.*)

§ 156. WOODEN FLOORS.—A wooden floor consists of planks nailed down on beams, called *joists*, which rest on wall-plates, and extend from wall to wall, across the narrower space or width of the floor. The joints between the planks may be rebated or grooved and tongued (see page 129, Figures 54 and 58) to prevent their opening out.

The simplest of all wooden floors (see Figure 99) is *the single-joisted floor*, which consists of a series of parallel joists (*bridging joists*) stretching across the room and resting on wall-plates; the planks are fastened directly to them. In regular dwelling-houses the joists should be placed 10 or 12 inches apart; the dimensions of the joists depend upon their length, the distance

between them, and the load they have to carry (see section VIII, page 254, *et. seq.*). When the span exceeds 8 feet, the joists should be strutted apart at mid-length (see Figure 99) to prevent their twisting, and to give rigidity to the floor ; when the span exceeds 12 feet, two rows of struts should be introduced, another row being added for every further length of 4 feet of span.

In the case of forest rest-houses, which are only used occasionally, the flooring joists need not be placed so close together. Deodar (*Cedrus Deodara*) joists 6 inches by 5 inches placed 2 or 3 feet apart are found practically to be sufficient for spans up to 12 feet. (*A. L. McIntyre.*)

FIG. 99.

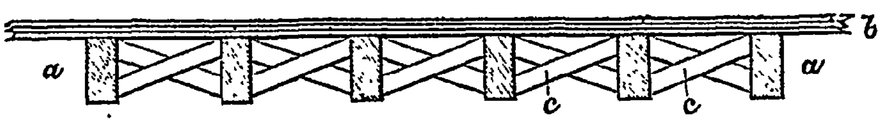


Figure 99 is a section through a single-joisted floor for a room 12 feet wide. a, a *are the joists* (*6"×3"*) *placed 12 inches apart from centre to centre;* b *is a floor board in longitudinal section* $1\frac{1}{2}$ *inches thick;* c, c *are herring-bone struts 2 inches square. Scale* $=\frac{1}{20}$.

Single-joisted floors should not be used for spans exceeding 15 feet to 18 feet, as they are liable to sag and bend.

In order to make a strong single-joisted floor the bridging joists should be thin and deep; if they are placed 1 foot apart, they should be at least 2 inches wide.

Tredgold[1] gives the following rule, which is based on experiment for determining the depth of bridging joists placed 1 foot apart :—

Divide the square of the length in feet by the breadth in inches and the cube root of the quotient multiplied by 2·2 for fir (a straight-grained timber) or 2·3 for oak (a strong cross-grained wood) will give the depth in inches.[2]

For a ground floor, the dimensions for joists made of sâl (*Shorea robusta*) for different bearings are given in the following

[1] *Op. cit.* p. 110

[2] The strength of fir and English oak relatively to that of the principal Indian timbers will be seen on reference to the table on pages 90 and 91, Part I.

table, taken from Hobart-Hampden's Notes on Forest Engineering, the joists being placed 3 feet apart from centre to centre:—

Span in feet.	Breadth of joist in inches.	Depth in inches.
8	$4\frac{1}{4}$	6
9	$4\frac{1}{2}$	$6\frac{1}{2}$
10	$4\frac{3}{4}$	$6\frac{3}{4}$
11	5	$7\frac{1}{3}$
12	$5\frac{1}{4}$	$7\frac{5}{6}$
13	$5\frac{1}{2}$	8
14	6	$8\frac{1}{2}$

If the joists are of deodar, the dimensions given for a span of 9 feet should be given to joists which have a span of 8 feet, and so on.

The dimensions of bridge joists, or planking for a floor, can be determined by the formula given below, which is deduced from the laws which regulate the amount of the deflection of a beam supported at both ends and acted upon by a weight applied at its centre, provided that the total deflection does not exceed in $\frac{1}{40}$ of an inch for each foot of the total length of the beam experimented on.[1]

$$b\,d^3 = W \cdot L^2 \times a \quad . \quad . \quad . \quad . \quad (1)$$

where b = breadth of the beam or plank in inches, d = its depth in inches, L = its length between supports in feet, W = load in lbs. applied at the middle and a

= ·0119 for English oak.[2]
= ·0099 for Indian fir (*Abies Smithiana or Webbiana*).
= ·0100 for Teak (*Tectona grandis*).
= ·0095 for Sâl (*Shorea robusta*).
= ·0099 for Sissu (*Dalbergia Sissu*).
= ·0112 for Deodar (*Cedrus Deodara*).
= ·0082 for Palnugra (*Borassus flabelliformis*).
= ·0090 for Casuarina (*Casuarina equisitifolia*).
= ·0102 for Anjalli (*Artocarpus hirsuta*).

1 Tredgold's carpentry by Hurst, 4th edition, 1883, pages 54 *et seq.*

2 The values of a have been deduced from M of the table given on page 228 of the Madras Civil Engineering College papers, No. X, Part III, 2nd edition, $a = \frac{40}{M}$ of that table.

In the case of bridging joists b should be taken as $0.7\ d$ (see page 66, § 47).

For example, to calculate the dimensions of deodar planking, begin by assuming the plank to be 12 inches (b) by 2 inches (d). Then the weight per square foot of the 2-inch deodar planking (7 lbs.) added to the weight of a crowd of people (168 lbs.), in all 175 lbs., will be W, the working load. The distance between the centre of the joists is 3 feet. We have made the plank 12 inches broad, and in consequence an area of 3 square feet rests on one joist, and the weight carried on the plank will be $3 \times 175 = 525$ lbs. Then we have from formula (1)

$$12 \times d^3 = 525 \times 9 \times \cdot 0112, \text{ or } d^3 = 4 \cdot 41$$
$$\therefore d = \sqrt[3]{4 \cdot 41} = 1 \cdot 64 \text{ inches,}$$

so that 2" planking will be ample.

The dimensions of a joist may be similarly calculated, the working load, being equal to the weight of the planking supported by the joists added to the weight of the maximum load which it may have to carry.

When the constant a is not known, the dimensions of the bridging joists and planks may be deduced from *the co-efficient of transverse strength* (P of the table on pages 90 and 91), in the same way as the dimensions of the roof timbers are calculated in Section VIII, page 254, *et seq.* of this Part.

Very few experiments have been made on the compressive strength of Indian timbers, but the values of P are fairly well-known.

§ **157.** In the case of ground floors, the hearth-stone of the fire-place can be supported on short walls constructed for that purpose; but for the floors of upper storeys special arrangements must be made to support the hearth-stone, and also to prevent the joists from being built into the flue of the chimney.

For the ground floor of a wooden house, the wall-plates should be supported on short projecting walls, or on corbelled-out projections from the face of the walling; 6 inches projection will be sufficient, and the joists which carry the flooring notched on the top of the wall-plates.

In upper storeys, where some of the joists would naturally run into the fire-place or the flue of a chimney, two short scant-

lings are introduced, called *trimmers* (see Figures 100 and 101, page 197), one on each side of the place to be avoided; one end of the timber rests on the wall-plate and the other is framed into the third joist from the wall, and the two bridging joists nearest the wall are framed into the outer side of the trimmers. The joist into which the trimmers are framed is called the *trimming joist*, and should be made thicker than the others, as it has to carry a greater weight. The hearth-stone should rest on a brick arch built from the wall to the trimming joist.

Two iron rods pass through the trimming joist and are embedded in the walling in order to resist the thrust of the arch. The ends of the tie rods should be bent down 9 inches and built into the wall. This is not shown in Figure 101.

FIG. 100.

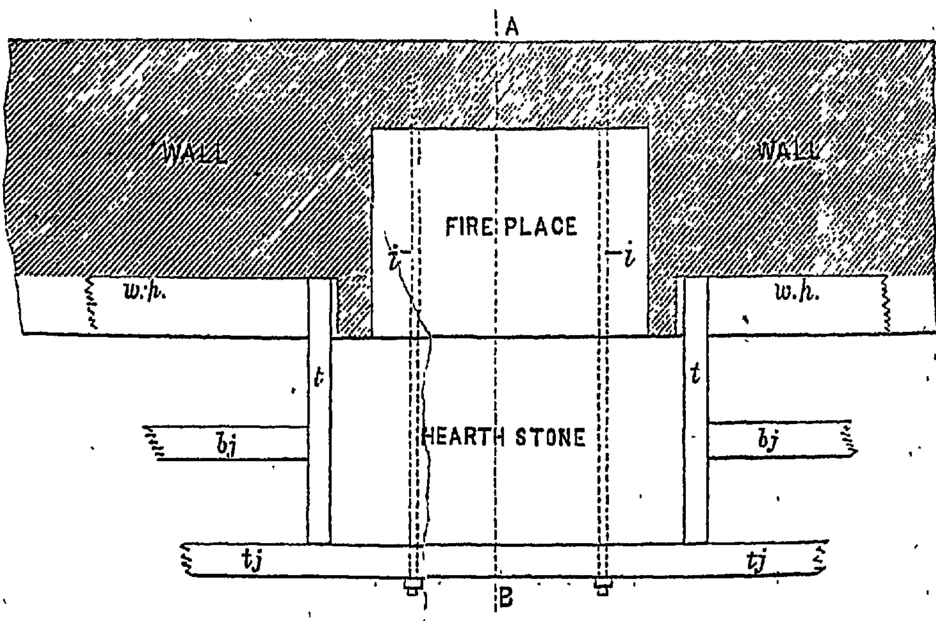


Figure 100 shows in plan the method of trimming the bridging joists so as to avoid a fire-place. bj, bj *are the bridging joists;* t, t *the trimmers;* t j *the trimming joist;* w,p. *the wall-plate;* i, i, *the iron bolts added to resist the thrust of the arch;* h *the hearth-stone;* f, *the fire-place; and* a, *the arch which supports the hearth-stone. Scale* = $\frac{1}{24}$.

FIG. 101.

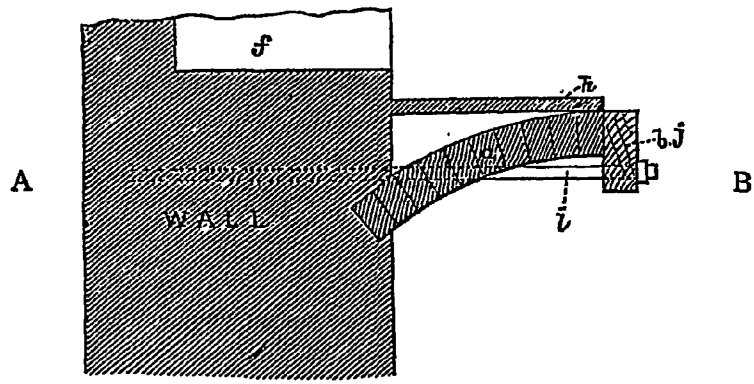


Figure 101 is a vertical cross section on the line A B *Fig. 100. The letters used are the same as in that Figure.*

§ 158. DOUBLE-JOISTED FLOORS.—For spans greater than 15 feet, the bridging joists, instead of spanning the whole distance from wall to wall, are supported by intermediate beams (*binders*), which rest on the walls. Binders should not be supported by the walling directly above an opening for a door, window, etc., if this can possibly be avoided. The binders should rest on *templates* (small slabs of stone, 2 or 3 feet long and 2 to 6 inches thick) let into a recess built in the wall; or if these cannot be obtained on wall-plates placed on projections built out from the wall or on short projecting walls.

Wall-plates 4½ inches wide by 3 inches deep will be sufficient for a span of 20 feet; the dimensions of the wall-plates should be increased proportionately with the span and the consequent size of the joists.

§ 159. PROTECTION AGAINST DAMP.—In damp climates special precautions are necessary to prevent moisture from the ground creeping up the walls and affecting the floor.

Dampness can be kept out to a great extent by raising the floor off the ground, and by constructing flues underneath it. These flues are made by building beneath the floor parallel walls one foot apart, extending across the building from main

wall to main wall, in which openings are left at one or two feet above the ground level to allow the air to circulate freely under the floor. Free circulation of air is provided by merely making holes in the main walls opposite one another. These openings are usually covered with pieces of iron grating to prevent vermin from entering and living under the floor.

A layer of asphalte (see page 150, § 121) or of glazed tiles, or 2 or 3 thicknesses of non-porous slates, introduced at 6 to 9 inches above the ground throughout the thickness of the wall, will effectually prevent the moisture in the ground from rising into the walls.

In the case of houses built of wood, the small stone walls, usually 2 to 3 feet high, upon which the bridging joists rest, afford the necessary ventilation; these walls should, if possible, be built in the direction of the prevailing wind.

The protection of buildings generally against white-ants has been discussed on page 150, § 121; so nothing more need be added here under that head.

SECTION V.—STAIRS.[1]

§ 160. A detailed description of the different forms of stairs in use is far beyond the scope of this work. As however Forest Officers may often require to construct simple stairs, some of the general principles of construction, with such details as are necessary, have been compiled from the existing standard works on the subject for their guidance.

§ 161. STAIRS are arrangements of steps for conveniently ascending and descending from one level to another, they are generally constructed either of stone or wood. Stairs may also be made of masonry or brick-work, supported on arches, or else solid, and in this case do not require any particular skill to construct, provided the relation between the *tread* and the *riser* is correct.

The following are some of the more common terms used in conection with stairs :—

The *stair-case* is the chamber or space which contains the

[1] Practically the whole of this section has been adapted from Chapter V of Part II (Edition of 1891) of "Notes on Building Construction" (Rivington's Series), the South Kensington Manual.

stairs. This may be a room the exact size required, the wall of which surround or support the steps. Or the stairs may be constructed in a large apartment, openings being left in the upper floors, so as to allow headway for persons on the steps, and to furnish communication between the stairs and the different storeys of the building. In the latter case the stairs are usually placed against a wall and the opening in the floor above is trimmed round it, in the manner explained with regard to a fire-place (see page 196, § 157).

The *tread* is the horizontal upper surface of the step upon which the foot is placed.

The *rise* is the vertical height between two treads.

The *riser* is the face or vertical portion of the step.

The *nosing* is the outer edge of the tread. In most cases it projects beyond the face of the riser, and is rounded or ornamented by a moulding.

Fliers are the ordinary steps of rectangular shape in plan.

Winders are the steps of triangular or taper form in plan required in turning a corner or going round a curve.

A *flight* is a continued series of steps without a landing.

A *landing* is a flat resting-place at the top of any flight. If the landing extends right across the width of the stair-case, it is called a *half-space;* if half across the width of the stair-case, a *quarter-space.*

Newels are posts or columns used in some kinds of stairs to receive the outer ends of the steps.

The *hand-rail* is a rounded or moulded rail, parallel nearly throughout its length to the general inclination of the stairs and of such a height above the steps as to be conveniently grasped by a person on the stairs.

Balusters are slight posts or bars supporting the hand-rail.

§ 162. DIMENSIONS OF STAIRS.—The actual dimensions of stair-cases and steps are regulated by the purposes for which they are intended. The steps should not, as a rule, be less than 3 or 4 feet long, soas to allow two people to pass, but for general convenience may be made considerably longer. The angle of

ascent for a stair will depend upon the total height between the floors to be joined and the space that can be afforded in the plan. The wider the *tread* the less the rise will be. For ordinary purposes the *rise* should not be more than 7 inches or less than 5½ inches; while the *tread* should not be more than 12 inches or less than 9 inches. The width of the tread added to twice that of the rise, should not exceed 2 feet. The actual proportion between the tread and the riser is practically regulated by the space, as regards height and plan that is available for the stairs, and cannot always be fixed in accordance with the rules just laid down. The rules, however, should be borne in mind when a house is being designed in order to allow of good stairs being constructed. Flights should, if possible, consist of not more than 12 or 13 steps, after which there should be a landing.

§ 163. DIFFERENT FORMS OF STAIRS.—When all the steps are parallel to one another and rise in the same direction, the stair is called *straight*. When alternate flights rise in opposite directions, the ends of the steps composing each of these alternate flights being in the same vertical plane, so that there is no opening or well-hole between them, the stair is called *dog-legged*. When there is an opening or well-hole between the backward and forward flights, the stairs are said to be *Geometrical*. *Circular stairs* are composed of steps contained in a circular or polygonal stair-case, towards the centre of which they all converge. All the steps are necessarily winders. Circular stairs may also be made with the converging steps supported by a *newel* at the centre, or else rising around an open well, instead of resting upon a newel.

Straight stairs can only be used when there is a considerable length of space available for the stair-case, compared with the height to be gained. *Dog-legged stairs*, neglecting the space occupied by the landings, require about half the length and twice the breadth required by straight stairs. *Geometrical stairs* require a little more width and about the same length of space as a dog-legged stair.

Dog-legged stairs should have a half-space landing between the flights, if practicable. If the whole of the space must be taken up with steps, the tread of the winders will be very narrow near the balusters, and the stairs will be most inconvenient to ascend. Dog-legged stairs should not be used where winders are necessary, if there is room for a well-hole between the flights. The effect of the well-hole is that the winders converge to a point between the flights, and the treads have in consequence a certain amount of width even on the edge of the well-hole, and at a short distance inside, where a person ascending puts his foot, the winder is sufficiently broad to afford a convenient tread.

§ 164. STONE STAIRS.—Stone stairs are much simpler in construction than wooden ones, but the steps are much heavier and require substantial walls for their support. They become smooth under continued wear, and then are slippery and dangerous.

Stone steps are generally solid blocks; for external structures the tread should be slightly weathered (see page 149, § 120) or the stone set with a slight inclination outwards. Steps and landings which cannot be got out in one stone must be made of pieces jointed together. In some cases it will be necessary to support the landings on girders. Stone steps may be square in section, or the lower side may be cut away; this is sometimes useful where headway is required under the stairs, and also makes the stairs lighter.

Where large stones are not available, stairs may be constructed of brick-work, or masonry supported on arches of varying height, so as to give them the required inclination.

Fixing stone steps.—Stone steps may be supported at both ends on walls; or else may be built into one wall only, in which case they are called *hanging steps.* Hanging steps are soon destroyed by fire, they snap off at the wall. The lowest step of a stone stairs should be slightly sunk into the ground to prevent its sliding on its bed.

Steps supported at both ends are of most simple construction. Each stone is rectangular in section, of a height exactly equal to the rise, and in width a little more than the tread. They are about 12 inches longer than the width of the stairs, so that a length of 6 inches at either end may be built into the adjacent walls; when the walls do not rise higher than the sides of the stairs, the steps are of a length exactly equal to that of the total width of the stairs, and the ends are supported by walls built underneath them.

Hanging steps are fixed at one end only; the outer end projects, and is without support other than that afforded it by the steps below it. The fixed ends of the hanging steps should be let into the wall about 9 inches, and very solidly and firmly built in. If the ends of the steps are securely built into the wall, the steps cannot slide. Hanging steps may be built in as the wall is carried up, or the steps may be inserted afterwards. Sometimes about 12 inches of the walling above and below the steps is built in cement.

Stone stairs may be straight, dog-legged or geometrical. Dog-legged stairs are generally composed of hanging steps, the inner ends of which are built firmly into the wall, while the outer ends of the different flights are in the same vertical plane. There may be a half-space or quarter-space landing at the top of the first flight, or the whole space may be occupied by winders, thus adding to the height to be gained without increasing the area of the stair-case. A geometrical stair in stone consists entirely of hanging steps, the outer ends of which are built into the wall, while the inner ones abut upon the well-hole of the stairs. If constructed with no landing, the space being entirely filled with winders, the latter will be of a much better shape than in a dog-legged stone stairs.

§ 165. Wooden Stairs.—Wooden stairs are lighter than those of stone, and do not require such strong supports. They are also more elastic, and do not become so smooth under wear and tear as to be dangerous. They are, however, subject to decay, and may be more rapidly destroyed in case of fire.

The steps proper are supported on inclined scantlings of thick boards, called *strings.*

The string placed up against the wall and plugged to it is called the *wall string.* That at the end of the steps furthest away from the wall is called the *outer string.*

With short treads and risers these two strings are sufficient for stairs 3 or 4 feet wide. For wider stairs additional support may be afforded by *rough strings* introduced between the wall and the outer string. These should be about the same size as the bridging joists. Their upper surfaces may be slightly notched to receive the back edge of the tread, and pieces of board should be nailed to them so as to further support the steps.

The *wall string* is plugged to the wall. The upper and lower ends of the *outer string* are framed into newel posts (see page 199, § 161), as are also the first and last risers of each flight.

When the flight of steps extends uninterruptedly from one floor to another, the newels are attached to trimming joists (see page 196, § 157) provided among the floor joists to receive them. When the flight of steps is broken by a landing, additional newel posts should be provided on each side of the landing, extending the full depth between the floors. The trimmers (see page 196, § 157) which are fixed and wedged into the wall and project from them to carry the landing, are attached to these newel posts. The ends of the rough strings are framed into the trimming joists, or, if these are not available, into the trimmers.

The *wall* and *outer strings* may be *cut* or *housed.* In the former case rectangular notches are cut in them, each equal in depth to the rise, and in width nearly equal to the tread of a step. The boards forming the treads and risers are nailed to them. The outer string of a geometrical wooden stair is always *cut.*

In many stair-cases the strings, instead of being cut to receive the steps, are left with their upper surfaces parallel to

the lower, and grooves (*housings*) are cut on their inner sides to receive the ends of the treads and risers which are secured in their places by wedges.

§ 166. CONSTRUCTION OF WOODEN STEPS.—Wooden steps are formed of boards. The *risers* are united to the *treads* by joints. The riser should be tongued and grooved, or rebated (see Part I, page 129, Figs. 57 and 55) into the tread. The joint between the tread and the riser may be strengthened by small blocks of wood nailed into the inner angle.

The treads should project over the risers, and are usually finished with a rounded or moulded *nosing* (see page 199, § 161), the projection of the nosing is generally equal to the thickness of the tread.

The tread should be made of some hard wood, and may be 1⅛ inches thick for steps 4 feet long, the thickness being increased by ⅛ inch for every 6 inches added to the length of the steps. In very common stairs the risers are sometimes dispensed with.

In England the joints between the risers and treads are glued. In India glue will not stand the climate, and the back of the treads should be screwed to the lower edge of the risers. The landings are supported on ordinary floor joists resting on the walls and framed into the trimming joists which carry the heads and feet of the outer string of the stairs. Winders are only necessary where the plan of the stairs is such that it will not admit of a landing being made; and in this case the place, otherwise occupied by a landing, is filled up with steps (winders).

Winders are constructed as follows:—Joists called *bearers* are framed into the newel, with their outer ends resting in the wall of the stair-case. In the case of a large stair-case struts (*cross-bearers*) may be fitted between them to still further strengthen the structure. The risers rest on these bearers, and the treads are fastened to the wall string in the usual way and to the newel. Sometimes 2 or 3 joists parallel to the *fliers* going from wall to wall of the stair-case are substituted for the

bearers referred to above, and where the winders cross them, rough brackets for their support are attached.

§ 167. *Hand-railing.*—The height of the hand-railing should be higher on landings than on the steps themselves. They should be specially raised over the winders, particularly if they have a steep pitch. The height from the tread at the nosing to the upper surface of the hand-rail on the steps should be 2 feet 7½ inches. On landings a height of half a riser should be added to this. The upper surface of the hand-rail should be rounded. A common dimension for it is 3½ inches wide by 2½ inches deep.

The balusters may be nailed directly to the hand-rail. The hand-rail is supported by the balusters, which usually consist of wooden bars square (1 to 1½ inches side) or round in section.

The balusters may be dovetailed into the tread or fixed to the outer string. Generally two balusters are fixed on the end of each step, one flush with the riser and the other half way between the risers. On each of the narrow ends of the winders only one baluster is required.

§ 168. General Remarks on Planning Stairs.—Before planning or laying out a stair the following information is required, and is generally determined by the circumstances of the case:—

(1) The height of the stairs, *i.e.*, the vertical distance between the surfaces of the floors to be connected by the stair.

(2) The position of the first and last riser. These must be conveniently arranged in connection with the approaches, doorways, etc., leading to the stairs.

(3) The width and length of the stair-case available.

(4) The position of the doors, windows, etc., surrounding the stair-case. The steps must be kept clear of these. When these particulars are known, we can determine the description of stairs which should be adopted, bearing in mind the class of building in which the stairs are to be erected.

Having decided the kind of stairs to be constructed, some ingenuity and contrivance will be required in order to give them proper proportions, and at the same time to arrange them so as to fit the space available. A *good stair* should consist of flights running alternately in opposite directions, and each containing not more than 10 or 12 steps. All sudden alteration in length of flights, the introduction of single steps here and there, should be avoided. The landing between the flights should be of a length and width at least equal to the length of the steps. Winders should be avoided as much as possible, and the steps should all have the same rise. The rise and tread should be carefully proportioned. Care must be taken that when one flight passes under any other or below a landing there should be plenty of headway, and also that the steps are kept clear of all doors and windows on the stair-case. The stairs should be well lighted throughout their length.

§ 169. LAYING OUT THE PLAN OF STAIRS.—The height of the storey being known, a convenient height for the risers is first tentatively assumed. The total height to be gained, divided by this, will give the number of risers. The number of treads will be one less. The proper width for each tread (in proportion to the height of the riser) should then be determined (see page 200, § 162). If there is room in the stair-case for the required number of treads and the required landings, well and good; if not, the height of the riser must be increased and the width of the tread proportionately decreased; or the landing in the case of a dog-legged or geometrical stair must be entirely or partially replaced by winders. In laying out the winders, it should be remembered that the tread is inconveniently narrow near the balusters; consequently the treads of the winders should be made the same width as that of the fliers at a distance of 18 inches—or in the middle, in small stairs—from the balusters. This cannot always be accomplished in dog-legged stairs.

When laying out stairs practically, in the building itself, the height to be gained is carefully marked out upon a *storey rod* on which are marked equal divisions corresponding to the

number and height of the risers. A similar rod for the treads should be also used. A rod showing the width of the staircase, the length of the steps, the size of the newels and risers, and of the inner and outer strings should also be prepared.

SECTION VI.—ROOFS.

§ 170. In the construction of any building, one of the essential considerations which governs the whole design is the kind of roof to be supported. There are many kinds of roof and roofing materials, but roofs, so far as their construction is concerned, may primarily be divided into three principal classes :—

(1) Flat or terraced roofs.
(2) Arched roofs.
(3) Pent roofs.

The flat or terraced roof is a very simple and solid construction, and does not from its nature admit of any fundamental difference of patterns.

Arched roofs may consist either of one large arch, or of a series of low flat arches (*jack arches*). In the latter case the jack arches spring from iron beams resting on the tops of the walls of the building or room to be roofed in : the size of the beams depend upon the span of the arches. If the arches are small, the roof closely resembles a terraced roof.

Pent roofs include all forms of roofs built with sloping surfaces, and can be constructed in many different ways and of many different materials.

§ 171. Terraced Roofs.—The upper surface of a terraced roof is nearly flat, and the roof itself in consequence forms a very convenient place for sleeping when the weather is very hot.

Beams of wood, or iron girders, are placed across the rooms of the house to be roofed. The dimensions of the beams, and the interval between them, depend upon the size of the room and the weight which they have to bear.

Small scantlings, usually square in section, are placed upon the main wooden beams, and are laid the length of a brick apart from centre to centre, so that the bricks laid across them to form the substratum of the terraced roof may just abut against one other.

Flat tiles, 12 inches square and from 1½ to 2 inches thick, are preferable to bricks, if procurable, because they are lighter.

FIG. 102.

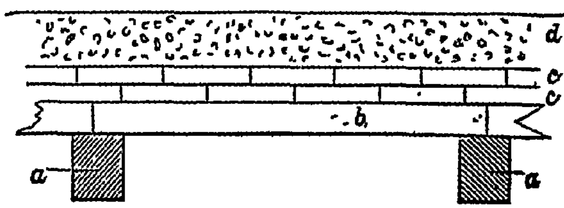


Figure 102 is a section through a terraced roof. a, a *are the main beams*; b *is a scantling, the scantlings are joined over the middle of the main beam, and* c, c *are the layers of tiles;* d *is the 5-inch layer of concrete which forms the upper surface of the roof.*

If tiles 1 inch thick are used, two layers will be required, and these should be made to break joint with each other. Their edges should be set in mortar. Over this place a layer of broken pieces of country tiling about ½ to ¾ of an inch thick, and on the top of this lay 3½ to 4 inches of fine concrete made, if practicable, from broken bricks of not more than ½ an inch gauge (1 inch is too large), or, better still, the fine nodules left from lime screenings of unburnt kankar. The layer of concrete should be well beaten and freely watered. When consolidated, but before it is dry, it should be "rendered" with the fine gruel-like sediment, deposited from lime mixed in *gur* (unrefined sugar) and *bel* (the fruit of *Ægle marmelos*) water, put on with a grass brush and smoothed over with a trowel. (*R. N. Hodges.*)

The upper surface of the concrete must be kept smooth and sloped outwards (½ an inch per foot), so as to allow the rain-water to run off easily. This slope may be obtained by slightly

raising one end of the beams which support the roof; or if the centre of the roof is to be the highest point, by nailing wedges of wood on to the beams on which the roof rests. The concrete, when laid, must not be too fluid. After the layer of concrete has been laid, the surface must be beaten with *thápis* (light wooden mallets) until it is sufficiently consolidated to cause the latter to rebound from its surface when let fall on it.

During the process of consolidation, the upper surface of the concrete should be sprinkled with water, in which molasses (*gur*) and *bel* (the fruit of *Ægle marmelos*) have been dissolved in the proportion of half a cask of water to 3½ seers of molasses and 2 seers of *bel*. On the completion of the beating process the surface of the concrete is sprinkled with water and worked to a fine polish, molasses and *bel* water being added. No plaster should be laid on outside the concrete. Any cracks which appear in the concrete may be filled and rendered water-tight with an intimate mixture of tar and rosin;[1] of cotton (2 oz.) cut up very fine, boiled linseed oil (10 lbs.), and slaked lime (20 lbs.);[1] or of linseed oil (4 lbs.), rosin (4 lbs.), and pumice stone (2 lbs.).[1] As soon as the consolidation of the concrete is completed, the upper surface of the roof should be covered with a layer of sand or fine earth 2 inches thick, upon which a layer of grass mats should be placed and kept constantly wet until the rains begin. It is assumed that such work will be begun in the cold weather.

Some people advocate terraced roofs with no parapets, so as to allow free play for the rain-water; but if sufficient allowance is made for the escape of the rain-water, a parapet may be added, and it certainly improves the appearance as well as the safety of the building. Where a terraced roof joins a wall, care should be taken to see that the concrete is thoroughly rammed, beaten, and united with the wall.

§ 172. In Madras terraced roofs differ in construction from that just described, in not having tiles or bricks extending from one joist to another. The joists are placed from 12 to 16 inches apart from centre to centre.

[1] Madras Civil Engineering College Papers, 2nd Edition, Part I, page 72.

Then a layer of bricks-on-edge arranged diagonally to the beams is placed over the joists (the bricks are about 6" × 3" × 3½") and the mason begins work from one angle of the room. The first brick or two rest on the wall. The mason then covers one side and end of a brick with stiff mortar and presses it into place, while he sits on a joist facing his work, and if the brick just placed in position is unsupported by a joist, he presses one foot against it while he mortars and places the next brick in position, then transfers his foot to it, and has both hands free to hold and mortar another brick. He thus works backwards and forwards completing one row from wall to wall before he commences a second row. The rows break joint as in an ordinary ½ brick wall. On the top of this brick-on-edge a layer of hydraulic mortar is laid, and on it a layer of flat tiles (about 4½ inches square). Sometimes a second layer of mortar and tiles is added. On the top of all a layer of from ½ to 2 or even 3 inches of hydraulic mortar is laid, the surface being polished with a pebble.

In the Kurnool District thin slabs of stone (1 inch thick) are laid on the joists, and are covered with from 3 to 6 inches of concrete and a coat of lime plaster. A similar roof is used for verandahs with a rise of 1 in 4. Along the eaves of the roofs is a raised ledge of plaster or concrete to serve as a gutter, openings being left at intervals to allow the water to escape. These should be furnished with open spouts to throw the rain water well clear of the wall of the building. The ground on to which the water falls is protected by slabs of stone, from which a channel runs to take the water away from the basement of the building. (*F. A. Lodge.*)

In Sindh, as well as in some parts of the Madras Presidency (Kistna District), terraced roofs are made with mud instead of concrete as described above. In Madras beams are placed from one wall to the other and rafters above them in the usual way, while over the rafters are placed roughly-shaped planks about 1½ feet long by 6 inches wide and 1½ inches thick forming a wooden ceiling. A covering of leaves and twigs is placed on these planks, and above this layer comes a covering of clay about 9 inches thick. This clay (locally known as *Pati matti*) is prepared as follows:—All small stones and other impurities are first removed from the clay, so as to prevent its cracking as it dries. It is then mixed with hoes with a small quantity of water and left alone for some hours, when more water is added to it, it is then worked into a pasty consistency. This pasty material is then laid evenly over the leaves and twigs by means of wide-mouthed pans. About three days afterwards the clay begins to crack, and the cracks are filled up with dry earth. On the fourth day *Tsandu* (salt-earth) is evenly spread over the roof to a depth of 1½ to 2 inches. The mud walls, which have only been completed to the bottom of the beams, are now raised up to within 3 inches from the upper level of the roof, and slates (*napa*) are arranged along the walls in two layers, projecting about a foot beyond the outer surface of the wall, so as to protect them

from rain. The upper layer breaks joint with the lower one. A mud wall about 1 foot high and 1 foot thick is built on the slates all around the house and at the bottom of this earthenware spouts are sometimes placed to allow the water to drain off the roof. (*A. W. Lushington.*)

In Sindh[1] grass mats made from *Saccharum spontaneum* (*kânk*) and *Saccharum sara* (*sûr*) are substituted for the covering of leaves used in Madras, and a layer of cow-dung and sandy earth, 5 inches deep, is placed on it and beaten until the surface is smooth. The upper surface of the roof is made to slope outwards slightly so as to allow the rain to run off easily. A layer of sun-dried bricks, 2 inches thick, laid in mud, is then added and roughly plastered, any cracks being filled with mud when the roof is dry.

§ 173. TERRACED ROOF FOR A VERANDAH.—In the case of verandahs or roofs of small span, small scantlings (*karris*) are sufficiently strong to support a terraced roof. The scantling of the timbers used will depend upon the span of the roof and the weight of the roofing material. For spans up to 8 feet simple joists may be used to support the roof, but where the span exceeds 8 feet it is more economical to use beams and battens in the usual manner. The dimensions of these may be determined in the manner described in Section VIII., page 254, *et seq.*

The scantlings, which support a verandah roof, as well as the roof itself, are often introduced into the wall of the building. The higher ends of the scantlings are embedded to a depth of about 9 inches in the wall of the building, while the lower ones rest on walls, or wall-plates supported by posts or pillars. A better way of supporting the upper ends of the rafters of the verandah is to construct pillars or posts to support them, instead of building them into the wall. Or else to construct a corbel of stone or wood (see page 156) for this purpose. The roofing in contact with the wall does not then enter it; and to prevent leaking at the junction a projecting course roof bricks should be laid in the wall at a suitable height above the rafters, and the space between this and the upper surface of the terraced roof filled with concrete.[2]

[1] Shokiram Pribdas, Extra Assistant Conservator of Forests, Hyderabad, Sindh.

[2] Civil Engineering College Papers, No. X, Part I, page 71, 2nd Edition, Madras, 1877.

§ 174. Terraced roofs have the disadvantage of being very heavy and of requiring high and specially strong walls, thus adding considerably to the volume of the masonry required. They are themselves expensive to construct, and are often very difficult to keep water-proof. It is impossible to make the roof water-tight if the wood-work is unseasoned.

The following rule for determining the dimensions of joists and beams for a terraced roof (weight allowed for being 100 lbs. per sq. ft.[1]) is given in the Madras Civil Engineering College Papers. The dimensions of the beams used may also be calculated in the manner described in Section VIII, page 254, *et seq.*:—

For every foot of unsupported length in a beam, allow . . . $\frac{3}{4}$ inch depth and $\frac{1}{3}$ inch breadth.

For every foot of unsupported length in a joist, allow . . . $\frac{1}{2}$ inch depth and $\frac{1}{4}$ inch breadth.

§ 175. ARCHED ROOFS.—When the dimensions of a room are such that it is difficult to get the large timbers necessary to support a terraced roof, an arched roof may be constructed. Arched roofs are said to be hotter than terraced roofs, but are more durable and equally water-proof. The roof may be made of one large arch, or of a series of small arches (called *jack-arches*) supported on girders.

When the span is more than 20 feet, a series of jack-arches supported by girders is generally preferable.

If the roof is made of one large arch, the arch may be either semi-circular, elliptical or segmental. If the last form be adopted, the walls of the building must be considerably strengthened to take the thrust of the arch.

If the roof is constructed of a number of jack-arches, these may be either semi-circular or segmental, and should spring from suitably cut bricks laid on iron girders, or old iron rails used as beams. If old iron rails are used, they should be given a *camber* (see page 184, § 146) of 2 or 4 inches[2] at the centre, while

[1] Civil Engineering College Papers, No. X, Part I, page 71, 2nd Edition, Madras, 1877.

[2] R. N. Hodges, Superintending Engineer (Railway Construction Branch).

the ends of the rails embedded in the walls should be rigidly backed with masonry to prevent spreading and consequent loss of camber.

If it is decided to roof the building by means of one single arch, great attention must be paid to the construction of every part of the building, in order to ensure its stability and to prevent it from settling unequally. If the arch is segmental in shape, the walls must be made sufficiently strong to bear its thrust, as well as the weight of the roof itself; or the lateral thrust of the roof must be counteracted by wrought iron tie-rods.

The thickness of the walls which support the roof will vary with the weight of the roof and the thrust of the arch or arches of which it is composed. The best materials only should be used in the construction of arched roofs and only skilled workmen should be employed. The mortar in the walls should be allowed to set before the roof is begun. The floor should be laid after the completed building has finished settling.

In constructing an arch the best and hardest bricks only should be used, the joints should be very fine and even, and the mortar should be made with cement or good hydraulic lime. Holes should be left in the roof for ventilation, unless suitable provision has been made when building the walls. The mortar in the arches should be allowed to set thoroughly before the centre is removed.

The number of brick-layers employed should be sufficient to carry on the work in even courses, so that the arch may be built up symmetrically from either springing. The arch should be carried up from both sides at the same time, the courses being made to break joint with each other. If the arch is constructed in two layers, the joints of the second layer should alternate as far as practicable with those in the first layer. The last course, which forms the key of the arch, should be put in very tightly; this may be done by leaving a little less space than the thickness of the last brick, and widening the aperture

by means of planks and wedges until the bricks can be placed in position without using much force.

The question of the construction of the centring on which an arch is built has already been considered (see page 186, *et seq.*). After the centring has been removed or "struck," the arch should be allowed to settle. If the arch is an important one, pile dry bricks on the haunches and crown and leave them there for two or three days, then remove them and proceed with the work that remains to be done. The spandrils, especially in the case of semi-circular arches, should be filled up as the arch rises.

§ 176. When the roof consists of a single arch, wrought iron tie-rods must be inserted passing from the back of the block forming the skewback surface to the corresponding skewback block, to resist the lateral thrust of the arch ring. Similarly when the roof consists of a series of arches resting on girders, the lateral thrust of the outer arch springing from the outer wall must be resisted by wrought iron tie-rods, passing through the girder and through the outer wall, where a large washer plate 9 to 12 inches square, of cast iron, should be placed between the nut of the bolt and the wall surface. If the arches are segmental, the two last girders should be tied together by wrought iron rods, placed horizontally 6 or 7 feet apart at mid height of the skewback surface and passing through the arches so as to counteract the thrust of the last segmental arch on the external wall. These tie-rods have threaded ends, and the nuts are screwed tight against large washer plates. Where two segmental arches spring from the one girder, their thrusts will more or less neutralize each other, and the resultant of the two thrusts of the arches on the girders will pass vertically down through the girder itself and will not affect the equilibrium of the structure. The diameter of a tie-rod will vary with the span and the thickness of the arch; if the rise of the arch is one-fifth of the span, the thurst will be one-half of the weight of the arch. For example, suppose we have an arched verandah 30 feet long, the thickness of the arch being, 9 inches and the

arches 6 feet along their axes, the total weight of the roof per foot of length will be—

$$6 \times 1 \times \tfrac{9}{12} \times 120 = 520 \text{ lbs.}$$

If the weight of a cubic foot of brick-works weighs 120 lbs., and as the verandah is 30 feet long, the total wight of the roof will be—

$$540 \times 30 = 16{,}200 \text{ lbs., or } 7{\cdot}23 \text{ tons.}$$

Half of this will be the horizontal thrust, that is, 3·62 tons. The safe tension load for wrought iron is 5 tons per square inch, so $\frac{3{\cdot}62}{5} = {\cdot}724$ square inches, or 4 ties, of ·181 square inches each, will be sufficient to resist this thrust; in practice we should use four bars, each ½ inch in diameter.

§ 177. The following information regarding the use of rails for arched roofs has been communicated by R. N. Hodges, Esq., Superintending Engineer (P. W. D.), Railway Construction Branch :—

For rooms of from 16 to 18 feet span flat-footed rails may be used, instead of rolled iron girders for supporting jack-arches; the rails must be given a camber of form 2½ to 3 inches, and the ends must be carefully backed in the walls to prevent their spreading. If unchambered rails are used they will not be strong enough to support the weight of the jack-arches.

In this way a room 18 feet span may be covered with jack-arches of brick-work, the rails (weight 62 lbs. per lineal yard) being placed 4 feet apart, and the thickness of the jack-arches being 4½ inches (half a brick). With jack-arches roofs give pleny of slope to the roof so as to ensure rapid drainage. Do not make the roof flat, like a terraced roof with battens, but let the roof follow the waves of the jack-arches. If this is done, the chance of leakage is decreased, and the weight of the roof is also lessened.

When flat-footed rails are used, the rounded surface

should be placed on the wall, and the jack-arches should rest on the flat foot of the rail.

§ 178. Pent roofs generally are constructed of much lighter materials than arched or terraced ones, and do not consist of a practically impervious mass of masonry, but are made of comparatively light materials arranged overlapping one another so as to allow the rain to flow down their sloping surfaces. The whole of the roof surface is supported on a suitable frame-work below. They are made of different shapes, of which the following are some of the more simple and elementary forms:—

Lean-to roof.—A lean-to roof is one which only has one side or slope (see Fig. 103), such as would be used for a verandah added to a house after it had been completed.

FIG. 103.

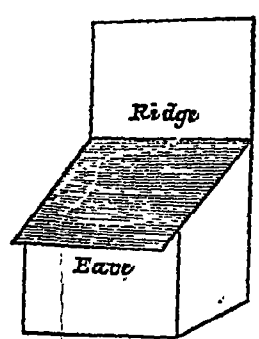


Fig. 103 is a sketch of a lean-to roof. The shaded portion is the roof.

Gable roof.—When the end walls of a building are carried up to the ridge so as to meet the roof, as in Fig. 104, page 217, the roof is called a gable.

FIG. 104.

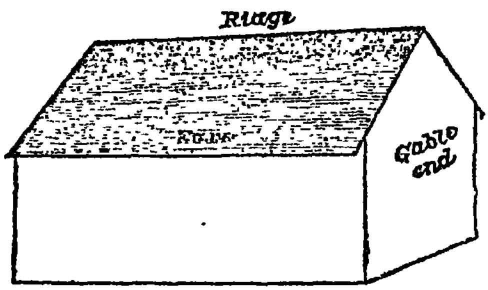


Fig. 104 shows a house with a gable roof. The roof surface is shaded.

Hipped roof.—When the end walls are not carried up higher than the side walls, and the roof is sloped down to meet the end as well as the side walls, the construction is called a hipped roof (see Fig. 105). The rafters, which are carried from the end of the ridge on to the angles of the wall at the end of the building are called "*hip rafters*"; the short common rafters which are fitted into the hip rafters and rest on the wall-plates are called *jack raftere.*

FIG. 105.

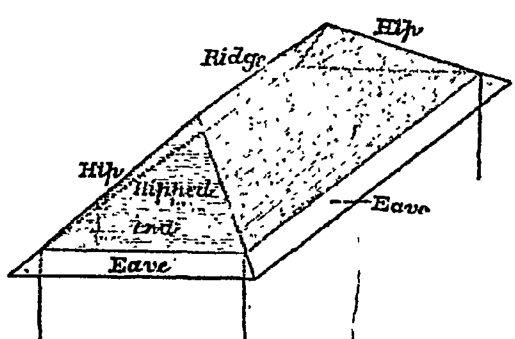


Fig. 105 shows a hipped roof. The actual roof surface has been shaded.

When there is no ridge piece, and all the upper ends of the hip rafters meet at the same place, the roof becomes pyramidal in shape.

The slope of a pent roof, *i.e.*, the angle at which the roof surface is inclined to the horizon is called the *pitch* of the roof.

The pitch of a pent roof may be expressed either by the angle which the surface of the roof makes with the horizon, or else by the ratio which exists between the *rise* (the vertical height of the ridge of the roof above the top of the walls of a building) of the roof and the *span* (the horizontal distance between the walls) of the building.

The pitch of a roof varies according to the climate and the nature of the roofing material used. Where snow falls the pitch of the roof must be specially steep, in order to prevent the snow from accumulating on it, and so adding to the weight which has to be supported by the roof timbers. In localities where rain only is expected the pitch may be less; and where little or no rain falls the roof may be made—so far as the rain is concerned—almost flat. The rise given to a pent roof is rarely more than $\frac{1}{2}$ or less than $\frac{1}{8}$ of the span.

§ 179. ROOFING MATERIALS.—In the plains of India, the roofing materials in most common use for pent or sloping roofs of forest buildings are thatching grass, palm-leaves or tiles. Terraced and arched roofs are used in the better class of permanent buildings only. In the hilly and cooler portions of India, planks, wooden shingles, galvanized corrugated iron, and plain sheet-iron galvanized or painted, are largely used. Where good slates or thin slabs of stone are available they form good and durable roofing materials.

Galvanized (zinc coated) corrugated iron is steadily superseding shingles and thatching grass (where the climate permits) in the better class of forest buildings, on account of its greater durability and the increased protection which it affords against fire. The rise in the price of shingles also favours the use of galvanized corrugated iron in the hills.

Sheet-iron is also used for houses, because it is cheaper if not galvanized, and lighter than corrugated iron. Sheet-iron, if not galvanized, must, however, be painted on both sides in order to protect it from the weather, and this coating has to be renewed from time to time, whereas galvanized corrugated iron requires no additional protection against the weather whatever.

Sheet-iron, if properly and regularly painted, is fairly durable. It is much lighter, and consequently weaker, than corrugated iron, but if not properly and regularly painted is soon eaten through by rust. When old, it is liable to be dented or pierced by hail during the heavy storms which visit the Himalayas at some seasons of the year.

In consequence of the constant attention and inspection required by sheet-iron, its use cannot be recommended for forest buildings in out-of-the-way places, which are only occasionally visited by a controlling officer. It is undoubtedly suitable for light roofs in a station where economy in initial outlay is of importance.

For small buildings, in the hills, planks are better than slates or slabs of stone, as it is very difficult to keep the latter in good repair. Monkeys, snow, and storms of wind continually disarrange them.

Tiles are used very largely in many parts of the plains of India, and form a cool and comparatively cheap roof. A tiled roof is almost as cool, and not nearly so heavy, as a terraced roof; and if properly constructed is much more durable and fire-proot than a thatched one. A thatched roof is, however, considered to be one of the coolest that can be constructed. Professional thatchers (*gharamis*), however, cannot always be obtained in out-of-the-way places.

If tiles are made of poor, sandy clay they will be light, porous and liable to be displaced by wind if not firmly placed in position.

§ 180. THATCHED ROOFS.—Thatched roofs are very largely used for forest buildings, though their use is prohibited, by Government order, in buildings constructed by the Public

Works Department, on account of the danger of fire to which they are exposed. A thatched roof consists of two parts—(1) a frame-work of bamboos similar to that used to support a tiled roof; and (2) a layer of grass placed on and fastened to the bamboo frame-work. The frame-work is usually made of split bamboos tied to each other and to the roof timbers with string. A layer of common mats may with advantage be laid over the bamboo frame-work, in order to make the inside of the roof lighter and cleaner.

A pitch of 35° (which is equivalent to a rise of $\frac{7}{20}$ of the span) is recommended; while one of 36° 52′ (which is equivalent to a rise of $\frac{3}{8}$ of the span) is found to answer well and simplifies the construction of the roof, since if this angle be adopted the ratio of the rise, $\frac{1}{2}$ span and sloping surface of the roof, to one another are as 3 : 4 : 5.

The *frame-work* consists of rows of whole bamboos, if small (or split ones if large), placed horizontally about 3 feet apart from centre to centre. On these, and crossing them at right angles, are tied bamboos placed 9 inches apart, and on these again split bamboos are placed diagonally at intervals of 6 inches. The bamboos are tied to each other with string at their points of intersection. This frame-work rests on and is firmly secured to battens or whole bamboos, placed 3 feet apart supported by the purlins or rafters of the roof truss.

Where large bamboos are available, they may be used for rafters instead of sawn timber. Freshly cut bamboos are often subject to the attacks of weevils, and should not be used. If only fresh bamboos are available, they should be cut when there is no moon (see page 88, § 61) and, if practicable, should either be totally immersed in water for a week, or else well smoked before being placed on the roof truss. The frame-work may be prepared on the roof truss itself, or on the ground, and when complete, placed in position on the roof-truss. Small repairs to the frame-work may be done without removing it from the roof timbers, but where the repairs required are consider-

able, the frame-work should be lifted off from the roof, taken to pieces, the decayed portions removed, and the whole frame work reconstructed and replaced on the roof truss.

The best *grass* for thatching purposes is one which is strong, tough, flexible, long, and at the same time fairly durable. A fine grass usually lasts longer than a coarse one.

The methods of constructing a thatched roof in India vary greatly in different provinces and districts, and consequently only that in use in the Dehra Dun district, and North-Western Provinces generally, has been described.

In the Dehra Dun District the usual thickness of the covering of grass for a thatched roof is 9 inches, composed of 3 layers, each 3 inches thick, closely and tightly packed together. Care is required to see that the proper thickness of grass is kept up from the top to the bottom of the roof, as contractors frequently make the roof thinner towards the top where they hope this defect may escape notice. If the grass is well laid, it should bear the weight of a man without perceptibly sinking. The grass is put on the roof in horizontal layers beginning at the eaves and working upwards to the ridge of the roof, and is kept in position by being placed between battens made of split bamboo, tied by string, at intervals of 9 inches, to the bamboo frame-work beneath. These battens should not be more than 9 inches apart. Each layer of grass should overlap two-thirds of the one beneath it. The grass is made up into small bundles (*tatties*) on the ground, from 1 to 6 inches thick. In the Dehra Dun District these bundles are fastened together with two small strips of bamboo, and are thus handed to the man who is thatching. This man places each bundle of grass separately in position on the roof between the battens, and then removes the slips of bamboo. The finished surface of the roof should have an even appearance. The eaves bundles are cut off square as the work proceeds. In the Dehra Dun District the bamboo battens which keep the grass in position are secured to the frame-work at one end first, and the string ties are passed through the bamboo frame-work by means of an iron rod, bent into the shape of a large curved surgical needle: the two free ends of the

string are left projecting above the frame-work, and are tied together over the split bamboo which keeps the grass in position after this has been laid on the roof. All the ties required for one layer of thatching grass are fastened to the frame-work before any of the grass is laid. These ties are covered over by the next layer of grass placed in position, and are not visible when the roof is complete.

The ridges and hips must be carefully bound over in order to make them water-tight: the way in which this is done varies from district to district. Where chimneys pass through the roof, great care must be taken to prevent the roof leaking around the chimney. This may be done by introducing a suitably bent sheet of iron into the masonry of the chimney and between the two small outer layers of the thatch, and constructing a small cornice (the under surface of which should be weathered and throated), around the chimney, level with the thatch on the upper side of the chimney.

The roof may be repaired by removing the upper layer of grass; repairing the lower layers, if necessary, to make the surface even, and then placing a fresh layer of grass on the roof. Six inches of thatch will, as a rule, keep out the rain very well indeed, and if the upper layers are removed from time to time, the lowest 3 inches often remains in serviceable condition for a very long time, and need only be replaced when it is decayed.

Thatched roofs with a low pitch decay very much more quickly than those with a fairly steep pitch, as in the former case the rain soaks into the thatch very much more, and thus causes it to decay. Roofs of houses in dense shade decay much more quickly than those situated where the air can circulate round them freely.

§ 181. When a roof is being thatched precautions must be taken to prevent the grass used being set on fire; the grass should be made up into bundles at a considerable distance from the building, and should be brought to the building as required. Waste grass should never be allowed to accumulate near the

[1] F. B. Bryant, North Western Provinces.
[2] F. A. Lodge, Madras.

building, but should be removed from time to time. All the grass which is not used should be removed at the end of each day's work to a safe distance from the building. No smoking should be allowed near the building or the place where the bundles of grass are being made up.

A rough scaffolding of bamboos may be put up around the building for the thatchers to stand on, and rope ladders may, if required, be supplied to the men employed in laying the grass.

§ 182. TILED ROOFS.—The slope of tiled roofs will vary somewhat with the quality of the materials used : the slope may be between 27° and 31°, corresponding to a rise of from about ¼ to ⅓ of the span.[1]

The tiles in most common use for roofs are pot tiles (see Fig. 106) or a combination of pot and pan tiles (see Fig. 107). Besides these simple forms of tiles, several more complicated kinds are used in different localities, many of which have been patented.

FIG. 106.

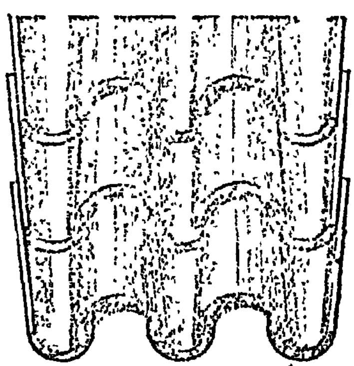


FIG. 107.

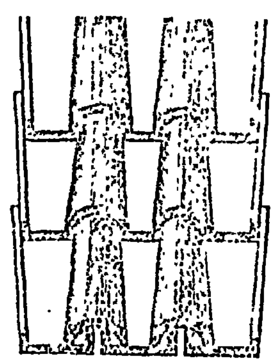


Fig. 106 shows how pot tiles are arranged to form a roof.
Fig. 107 shows the arrangement of pot and pan tiles to form a roof.

Tiles are commonly laid, directly, either dry or set in mortar on a frame-work of bamboos or mats fastened to the roof truss. Eaves-boards or small poles are fastened at the lower edges of

[1]Madras Civil Engineering College Papers, No. X, Part 1, 2nd Edition, page 78.

the roof in order to keep the tiles in position. If the tiles are laid dry, those forming the ridges and hips of the roof should be set in mortar. The tiles are laid from the eaves upwards to the ridge.

Roofs constructed, as described above, cannot be recommended, especially if common light porous country tiles are laid on the frame-work without mortar.

In order to construct a strong tiled roof, wooden battens 3 inches by 2 inches, should be fastened to the rafters of the roof truss. These should be placed 1 foot apart from centre to centre. Flat tiles, 12 inches square, should be laid on these battens abutting against one another, and should be set in strong mortar or cement.

Pot tiles, or pot and pan tiles, are then laid on the flat tiles, the three lowest tiles in each course, as well as those forming all hips and ridges, being set in mortar.

An eaves-board should be fastened to the lower edges of the roof to prevent the eaves-tiles from being displaced.

§ 183. The following information with regard to tiled roofs in Madras was kindly communicated by Mr. A. W. Lushington, Deputy Conservator of Forests:—

The rise of a tiled roof may vary between ⅓ and ⅙ of its span, if more than ⅓, the tiles would slip, and the *mortar-borders* (see page 226) which help to keep the tiles in position would be liable to crack; while if less than ⅙, the rain-water would not flow off the roof sufficiently quickly. The best slope, on the whole, is about 36½°, which is equivalent to the rise of the roof being ¼ of its span.

A tiled roof consists of a layer of flat tiles as a foundation, upon which either pot or pan tiles are placed. The flat tiles are laid abutting against each other, a small quantity of mortar being placed between each to keep them in position. These flat tiles are supported on thin battens (⅓ an inch thick by 1⅔ to 2½ inches wide) placed from 4 to 6 inches apart from centre to centre, parallel to the sides of the building, and nailed on to the rafters. Instead of battens a strong frame-work of bamboos may be used. If the bamboos are large, they are split, if small (one inch in diameter), they are used whole: the bamboos are tied together with string or coir rope. The use of bamboos, as a rule, reduces the expenditure considerably. A bamboo frame-work will last five years if tarred, and after that time the tiles, if

country ones, will probably require to be turned, and the frame-work can at the same time be renewed.

Eaves-boards fastened to the ends of the rafters, or mortar-borders, are necessary in order to prevent the tiles from slipping, and to give a finished appearance to the building.

Five different kinds of tiles are in common use in Madras (see Figure 108) :—

(1) The flat tile (*a*), which is ½ an inch thick and from 4 to 6 inches square.

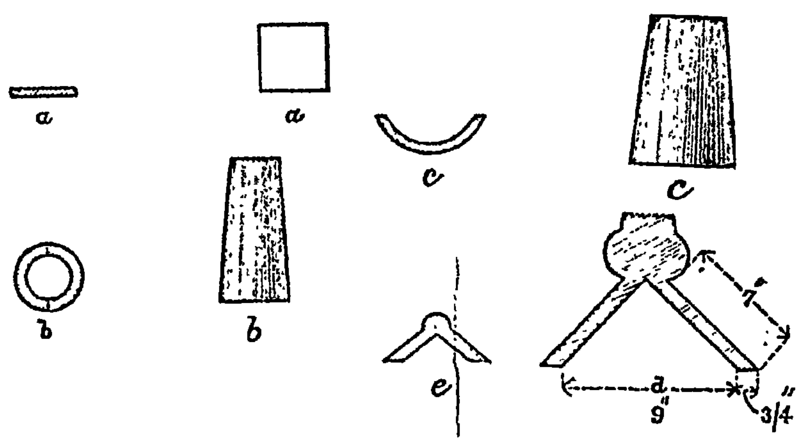
(2) The *pan* tile (*c*), which is a curved gutter-shaped piece of clay and is about 9 inches long and 6 inches wide.

(3) The *pot* tile (*b*) consists of a pipe of burnt clay, which is split in two halves when required for use.

(4) A large ridge tile (*d*), 18 inches long.

(5) A small ridge tile (*e*).

FIG. 108.



Figures 108, a-d, *show the forms of tiles in common use in the Madras Presidency.*

a, a *is a plan and cross-section of a flat tile.*

b, b *is a plan and end elevation of a pot tile.*

c, c *is a plan and end elevation of a pan tile.*

d, e *are cross-sections of the two forms of ridging tiles in common use. (Drawn by A. W. Lushington.)*

The inner surface of a tiled roof is generally whitened by dipping the tiles into whitewash before they are placed on the battens,

Along re-entering angles neither pot nor pan tiles are, as a rule, large enough to carry off the rain water, which falls on roof. Either a layer of mortar is put on the flat tiles, or V-shaped zinc or tin sheets (commonly old kerosine oil tins) are laid along all re-entering angles so as to form gutters before the pot and pan tiles are put in position on the roof. (*F. A. Lodge.*)

If pan tiles are used for the upper covering, they are laid in rows, at right angles to the eave of the roof, concave surface upwards, overlapping each other for a length of 2 or 3 inches, broad end up the slope, and running from the eaves towards the ridges or hips, so as to form a series of gutters; the edges of the successive rows of tiles are in contact (see Fig. 109). The battens of the roof are covered with tiles placed as described above, and then rows of pan tiles are placed, convex surface upwards and broad end down the slope, over the upturned edges of the rows first laid so that the rain cannot enter between them (see Fig. 109). The rows of tiles placed with their concave side upwards, form gutters by which the rain which falls on the roof is carried off, openings being left in the eaves-boards to allow the water to escape.

Fig. 109 shows a cross-section through a tiled roof as described above.

FIG. 109.

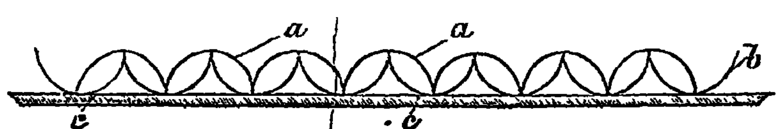


Fig. 109 is a cross-section (diagrammatic) through a tiled roof to show the arrangement of the tiles. a, a *are pan tiles placed convexly;* b, b *are pan tiles placed concavewise;* c, c *are the flat tiles placed on the battens or the bamboo frame-work.* (*Drawn by A. W. Lushington.*)

In order to keep the tiles in position, borders of ordinary mortar, 9 inches wide and from 4 to 8 feet apart, are placed over the tiles running from the ridge to the eaves of the roof following the direction of the rows of pan tiles: a similar border may be placed along the eaves of the roof, care being taken not to interfere with the flow of water off the roof. Borders 18 inches wide (9 inches on either side), run along the ridges, and might be employed, where the chimneys pass through the roof, in order to prevent the roof leaking around them.

When pot tiles are used instead of pan tiles, in order to make the roof more waterproof, two layers of tiles are often placed so as to form concave gutters, one in the hollow of the other, and then two courses of tiles, convex surface upwards, are placed over the upturned edges of the tiles first laid, so that the roof is four tiles deep.

Pot tiles are turned in the form of cylinders on a potter's wheel and are scored down each side (see Fig. 108*b*, page 225), before burning, but are only split in two after they have been burnt, and are required for use. A skilful brick-layer will split hundreds of such tiles without breaking more than 1 per cent. (*F. A. Lodge.*)

Pan tiles are moulded on a horse (see page 30, § 19), and though more expensive are usually much stronger and more durable.

A layer of pan tiles are always left so as to form a gutter along re-entering angles in the roof.

Ridge tiles are used along the ridges and hips of the roof, the larger ones being placed on the ridges and the smaller ones on the hips; sometimes borders of mortar are substituted for them. If the ridge tiles are placed on the top of the border of mortar, they effectually prevent the roof leaking at the hips, and give it a more finished appearance.

Pot or pan tiled roofs are sometimes made without flat tiles below, either for economy, or (as in kitchens, for instance) for the sake of ventilation. In such cases instead of battens small bamboos are fastened to the rafters as close as they will lie. (*F. A. Lodge.*)

The following are the rates given by the Public Works Department in the Kistna District for tiled roofing:—

	R a. p.		R a. p.
Best tiled roofing, with flat and pan tiles or pot tiles and mortar-borders, including teak battens, per 100 sq. ft.	15 0 0	to	19 8 0
Best tiled roofing, with pan tiles or pot tiles laid on bamboo batten and mats, per 100 sq. ft.	9 0 0		
Flat tiles, $6'' \times 6'' \times \frac{1}{2}''$, per 1,000	2 8 0		
Flat tiles, $5'' \times 4'' \times \frac{1}{2}''$, per 1,000	1 0 0		
Pan tiles, per 1,000	1 0 0	to	1 10 0
Ridge tiles, per 1,000	1 8 0		
Teak battens, per 100 running feet	2 0 0	to	2 4 0
Small teak scantlings, per cubic foot	2 12 0	to	3 0 0
Small scantlings, of other woods, per cubic foot	1 12 0		
Palmyra rafters, 14 feet long, each	1 8 0		
Palmyra rafters, 12 feet long, each	1 6 0		
Palmyra rafters, 10 feet long, each	1 4 0		

§ 184. SHINGLE ROOFS.—Shingles are rectangular pieces of split or sawn wood which are used for roofing purposes in Burma, the Andamans, and in many of the hill districts of India, in the same way as slates are in Europe and in other parts of

India. They are used chiefly in localities where suitable wood is plentiful and cheap, is not liable to be attacked by white-ants, and is not exposed to extremes of heat; where grass is not available, where tiles are not made, and where corrugated or sheet-iron is too expensive to be used.

The shape and size of the shingles used varies in different localities: a common size is from 12 to 15 inches long by 4 or 5 inches wide and ½ an inch thick. In the Jaunsar division (North-Western Provinces), shingles are made of sawn deodar (24 inches long by 6 inches wide by ½ an inch thick), and last from 15 to 20 years. The exposed portion of the upper surface of sawn shingles should be planed in order to allow the rain to run off quickly and not to sink in and cause rot. *(A. G. Hobart-Hampden.)* In the Darjeeling district the best shingles are split out of Katus *(Castanopsis rufescens, Hook. f. and Th.)*, while at higher elevations the Indian silver fir *(Abbies Webbiana)* is used. In Kulu, kail *(Pinus excelsa)* and in Kumaon and British Gharwal, Yew *(Taxus baccata)* is used.

In the Andamans shingles are sawn out of teak and Pyimma *(Lagerstrœmia hypoleuca)*. They are not planed, but before being placed on the roof they are dipped into a mixture of Gurjan oil [extracted from the wood of Gurjan *(Dipterocarpus turbinatus, Gærtn fil)*] and earth oil (unrefined kerosine). The roof is brushed over in the dry weather, every second year, with the above mixture. Good padauk *(Pterocarpus Indicus)* shingles if thus treated will last from 20 to 25 years. *(C. G. D. Fordyce.)*

Teak *(Tectona grandis)* shingles are made and exported in considerable numbers from Burma, and cost R25 per 1,000 at Rangoon for average good shingles. They are commonly sawn 15″ by 5″ by ½″ at one end, tapering to ¼″ at the other. Painted teak shingles were used for the roof of the new Secretariat buildings at Darjeeling.

A wood which is straight grained splits easily, seasons well, does not warp, and is fairly durable, will furnish good shingles.

In Europe shingles are always split out of the wood, and unless the grain is very straight this cannot be done. In India, however, the best shingles (*i.e.*, teak and deodar) are sawn out of the wood and not split.

In Jaunsar, battens, 3 inches by $1\frac{1}{2}$ inches, are laid across the rafters of the roof, at a distance of $\frac{1}{3}$ the length of the shingles used from each other, parallel to the eaves of the roof of the building, and the shingles are fastened to these by nails, two nails being placed in each shingle. The shingles should be previously bored to receive the nails. In Burma teak battens 2 inches by 1 inch placed 3 inches apart are used. The shingles are laid in horizontal rows beginning at the eaves, the first two rows of shingles being shorter than the third and subsequent rows, as shown in Fig. 111, page 230. Only one-third of each *full-sized* shingle is visible, the remaining two-thirds being hidden by other shingles, so that throughout the roof the shingles are always three deep.

FIG. 110.

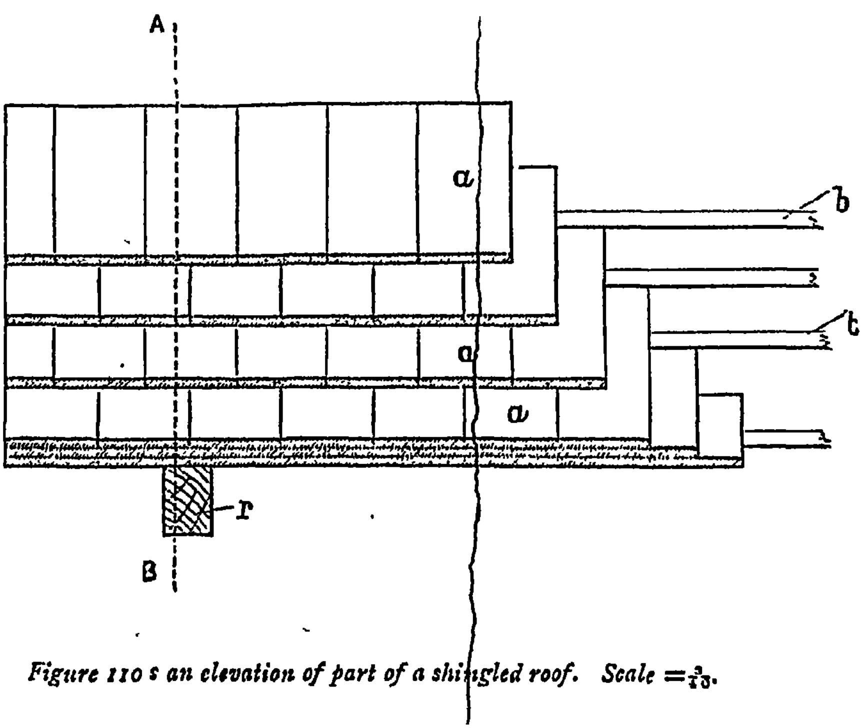


Figure 110 s an elevation of part of a shingled roof. Scale $=\frac{3}{10}$.

FIG. 111.

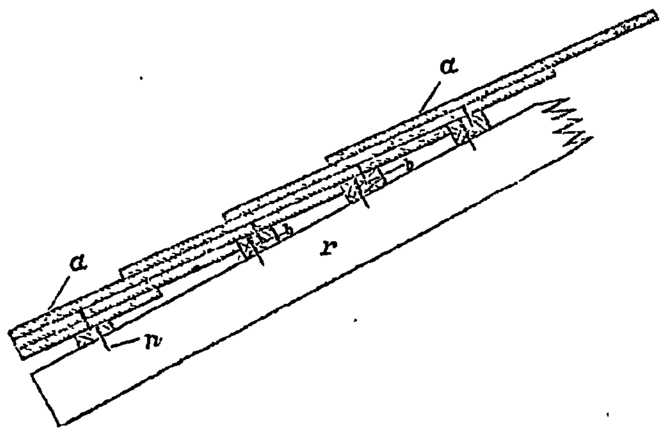


Figure 111 is a cross-section through the same roof along a line A B, Fig. 110, to show the construction of the roof. a, a, a *are shingles,* b, b, b *are battens;* r *is the rafter to which the battens are nailed;* n, n *are nails. Scale* $= \frac{1}{16}$.

Each row of shingles should break joint with the rows directly above and below it. In the case of hip roofs, complete shingles are placed in position along the hips and are then sawn off to the required shape. The ridges and hips may be covered with two planks, nailed to each other and the joint covered with a wooden bead, as shown in Fig. 112, or they may be covered with a piece of zinc ridging such as is used in conjunction with corrugated iron (see § 188, page 234). Only thoroughly seasoned wood should be used for shingles, or else the roof will be very liable to leak.

FIG. 112.

Fig. 112 is a cross-section through the boards which protect the ridges or hips of a wooden roof, showing how the joint is covered by a wooden bead. Scale $= \frac{1}{20}$.

§ 185. Shingle roofs may be made much more durable if the shingles are thoroughly painted after they have been placed in position; the paint must be renewed from time to time. In Burma shingles are never painted, they are dipped, prior to use, in boiling earth oil, and should be oiled again every year. *(H. Slade.)*

In the hills when the shingles are worn out battens may be nailed over them and corrugated iron placed over the old shingles; if this is done, the noise of the rain falling on the iron is very much deadened.

The pitch usually given to a shingled roof varies from 26° to 40°, the higher pitch being given where considerable falls of snow are of common occurrence. A portion of the roof of the fuel shed at Chakrata, which has a pitch of nearly 37°, was broken by the weight of the snow which accumulated on it in January, 1893. The pitch given to the roof of the new portion of the shed is 42½°.

§ 186. PLANKED ROOFING is generally used for godowns and out-houses only, as it very generally leaks; it is, however, easily and quickly made. The planks may be laid with their length either parallel to the ridge or at right angles to it; if in the former direction, the planks should be made to overlap. An extra layer of boarding fixed to the underside of the rafters will do much to stop leakage. If the planks are arranged vertically, they can be fastened directly to purlins laid on the walls of the building, and rafters can be dispensed with. Experience in the Punjab shows that a roof made of planks laid at right angles to the length of the ridge is less liable to leak than one where the planks are laid parallel to it. *(A. L. McIntire.)* Roofs made with planks laid at right angles to the ridge, consisting of a double layer of deodar *(Cedrus deodara)* planks, or of a layer of deodar planks on the top and one of blue pine *(Pinus excelsa)* or fir *(Abbies Smithiana or Webbiana)* below, does not leak much, if the timber used is well seasoned and free of knots. Battens ½″ by 2½″ should be placed over the joints of the top

layer. Screws are much better than nails for fastening the planks together. The pitch of the roof should be about 45°.

If the planks are laid parallel to the ridge, they should be screwed on to the rafters and should overlap each other, the lower edge should be bevelled (see Fig. 92, page 179).

Vertical planking may be made with planks laid slightly apart and the interval covered by a narrow plank, or the planking may be laid in two complete layers, breaking joint in the same way as shingles do.

If the joints between the planks be *caulked*, leakage will be practically impossible. *Caulking* consists of filling the joints with hemp or some other fibre and then pouring pitch, rendered liquid by heat, over it. Where Chir *(Pinus longifolia)* grows naturally very good pitch can be obtained by the destructive distillation of this wood in a closed kiln ; the resulting products being wood-tar and charcoal. Pitch may be obtained from the wood-tar, by driving off the water and other impurities it contains by the action of heat.

A roof, which so far as tried seems to be very suitable for rough buildings such as out-houses, is one made of a single layer of planks with a low pitch (such as 1 in 4) covered with birch bark, with a layer of clay over the latter. In Srinagar, where the rainfall is small, such a roof seems to be used for all kinds of buildings, and has been found superior to tiles, and effective enough against a heavy rainfall. But on account of its low pitch is not suitable for large spans in localities where there is a heavy snowfall, and the roofs cannot easily be cleared. *(A. L. McIntire.)*

§ 187. CORRUGATED GALVANIZED IRON ROOFS.—Corrugated iron is rolled sheet-iron bent into a series of parallel ridges and furrows, or corrugations: the corrugations increase very considerably the stiffness and strength of the sheets.

Galvanized iron is iron coated with zinc. The rolled wrought iron sheets should be coated after they have been corrugated; their quality depends upon the thickness of the iron, and the quality, evenness, and adherence of the coating of zinc.

The sheets of galvanized corrugated iron generally used in India vary in length from 6 to 10 feet, and in breadth from 2 feet 6 inches to 2 feet 9 inches, the width of the flutes, or parallel waves being 3, 4 or 5 inches (in India usually 3), and the depth of the corrugations one-fourth of the width. The thickness of the sheets are expressed in terms of the Birmingham wire gauge (B. W. G.). The following table gives the thickness and weights of the corrugated iron-sheets generally used in India. B. W. G. Nos. 22, 23, and 24 are chiefly used for roofs[1] :—

Birmingham wire gauge B.W.G.	Thickness in inches.	Weight in lbs per 100 sq. ft. of corrugated sheeting.
No.20	·035	224
No.21	·032	205
No.22	·030	185
No.23	·025	165
No.24	·022	150
No.26	·020	112

The slope of a roof constructed of corrugated iron may be as flat as 1 in 10. (*R. N. Hodges*.)

§ 188. The sheets of iron are usually fixed on to battens laid parallel to the walls of the building and fastened to the rafters of the roof truss. Deodar battens must not be used as they corrode the zinc. The distance between the battens depends upon the length of the sheets used. For long sheets one batten should be placed near either end and one in the middle; for smaller sheets one near either end will be sufficient. The battens are usually made 3 inches wide by 2 inches thick and of any convenient length. The sheets are laid in rows beginning at the eaves and working towards the ridge, so that the corrugations may be at right angles to the ridge and may serve as gutters for taking the water off the roof. An

[1] Notes on Building Construction (Rivington's Series), Part III, Materials, 2nd Edition, page 288.

overlap of from $1\frac{1}{2}$ to 2 corrugations laterally and 6 inches in the direction of the length of the sheets should be allowed, to prevent the roof from leaking (see Fig. 113).

It is usual to add 10 per cent. to the roof area to allow for these overlaps. *(R. N. Hodges.)*

FIG. 113.

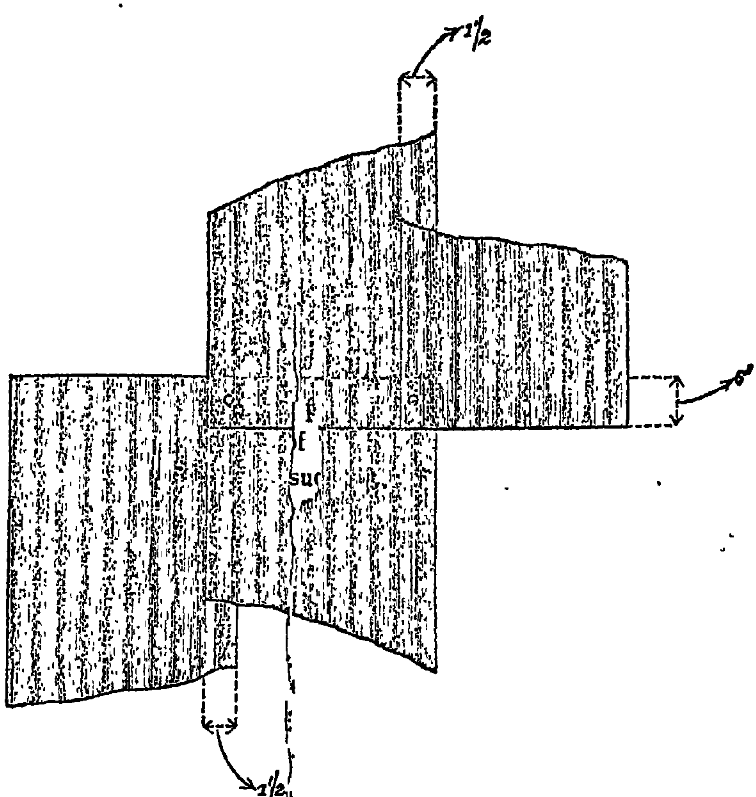


Fig. 113 shows the lateral and longitudinal overlap allowed when placing corrugated iron sheets in position on a roof. The dotted lines show the portions of the sheets which are hidden by those above them. Scale 2 feet = 1 inch.

The ridges and hips of the roof are protected by zinc or corrugated iron ridging, which is usually sold in lengths of 6 feet

and of either 3 or 6 inch side. These lengths should be given an overlap of 9 inches, and the joints set in white lead.

§ 189. Corrugated iron may be fixed on to the roof timbers in several ways. One of the most common methods (see Figs. 113, 114) is to fasten the sheets to battens by means of galvanized iron screws and washers; these screws are made 2, 2½, or 3 inches long.

FIG. 114.

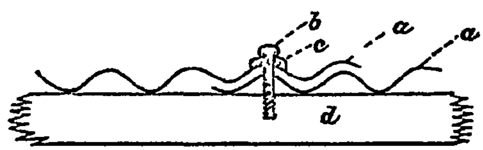


Fig. 114 is a cross-section showing the method of fastening corrugated iron on to the battens by means of screws and washers, shown in plan in Fig. 113. a *is the sheet of corrugated iron;* b *the screw;* c *the leaden washer;* d *the batten. Scale* = ⅛.

The sheets are placed in position and holes punched through them, from the underside, on *the ridges* (if the holes are made in the hollows, the roof is sure to leak) of the corrugations where required. A leaden washer is placed around the screw, which is then fixed to the batten below in the usual manner. If a leaden washer is not used, a little white lead should be put in the screw-hole, around the washer, to prevent the roof from leaking. The screws should be placed in the middle of the overlap. The smaller the number of holes made the less chance will there be of leakage. Three screws along either end of each sheet and one or two placed at equal intervals along the sides will be sufficient. The greater the number of screws used the greater will be the resistance offered to the pressure of the wind on the roof. The lead washers should project half an inch beyond the edge of the punched hole, and should be hammered to the same shape as the surface of the iron sheet to which they are applied. Where very strong winds are anticipated *wind-ties* may be added. These consist of strips of iron, 1½ inches wide and ¼ of an inch thick, fastened to the upper surface of the roofing material near the eaves of the roof, and screwed on to

the rafters: or else the corrugated iron sheets may be fastened at intervals by hook-bolts passing round the rafters or purlins as the case may be.

Guttering of galvanized iron or zinc, supported by iron staples, placed at intervals of 3 feet and fastened to the rafters may be added, to carry off the water which falls on the roof. If gutters are added, vertical zinc-coated piping will be necessary to carry off the water collected by them.

§ 190. Another method is to fasten all the sheets of iron together by means of galvanized bolts and nuts set in white lead, and to fasten the covering thus formed to the wooden rafters, purlins, angle iron or old rails which constitute the roof truss, by means of iron hook-bolts. The bolts and nuts take the place of the screws of the method illustrated in Fig. 114, page 235. The hook-bolts pass round the purlins or rafters as shown in Fig. 115, and are placed at irregular distances from one another, one bolt being allowed on an average to each sheet of iron. These hook-bolts offer very much more resistance to the force of wind than the screws described above, and obviate the necessity of battens.

FIG. 115.

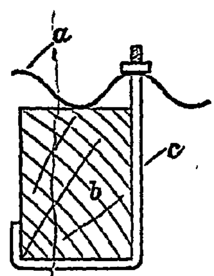


Fig. 115 shows the method of fastening corrugated iron on to the rafters of a roof truss without the use of battens. a *is the sheet of corrugated iron,* b *the rafter in section, and* c *the hook-bolt which fastens the sheet to the roof timbers. The bolts and nuts by which the individual sheets are fastened together are not shown. Scale* $= \frac{1}{8}$.

§ 191. In order to avoid the side overlap, the edges of the sheets may be turned upwards (see Fig. 116), a small wooden batten placed between them, and a roll of zinc passed over

them, and kept in position by a small iron clip fastened to the batten.

FIG. 116.

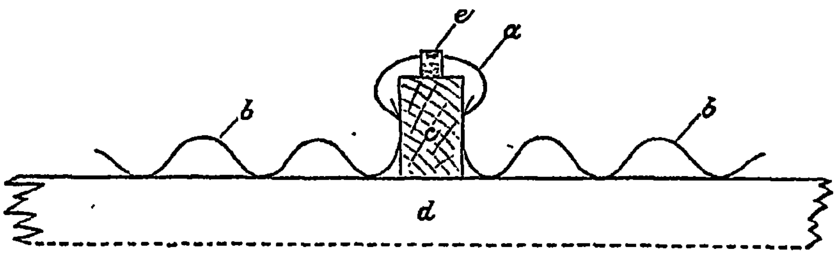


Fig. 116 is a section to show another way in which sheets of corrugated iron can be joined, so as to avoid the sheets overlapping. b, b *are two sheets of corrugated iron;* c *is a batten $2\frac{1}{2}$ inches by $1\frac{1}{2}$ inches;* a *is a roll of zinc covering the upturned edges of the sheets of corrugated iron;* d *is part of one of the purlins on which the battens rest;* e *is an iron clip added to keep the roll in position. Scale$=\frac{1}{8}$.*

The zinc roll may be bent to the required shape over an old iron rail, or by means of a special machine if the area of roofing to be dealt with is sufficient to justify its construction. The great advantage derived from this method of fixing corrugated iron on a roof truss is that there are no holes made in the sheets. Any holes which are made are always liable to become larger owing to the expansion and contraction of the sheets with sudden changes of temperature. If the roof is dismantled, the sheets and rolls can be used again without waste.

§ 192. Houses in the plains roofed with corrugated iron are apt to become very hot. Such houses may be kept cooler by providing a passage for the escape of the hot air, along the ridge of the roof, as well as along the tops of the walls. The space along the ridge may be obtained by allowing the ends of the rafters to project a foot or two beyond the ridge, and placing corrugated iron on battens fastened to the projecting ends of the rafters as shown in Fig. 117, page 238. Vermin can be kept out of the opening thus made along the ridge by fitting the spaces between the projecting ends of the rafters with fine wire

gauze. Where dust storms are common, a ventilator along the ridge is, however, objectionable.

FIG. 117.

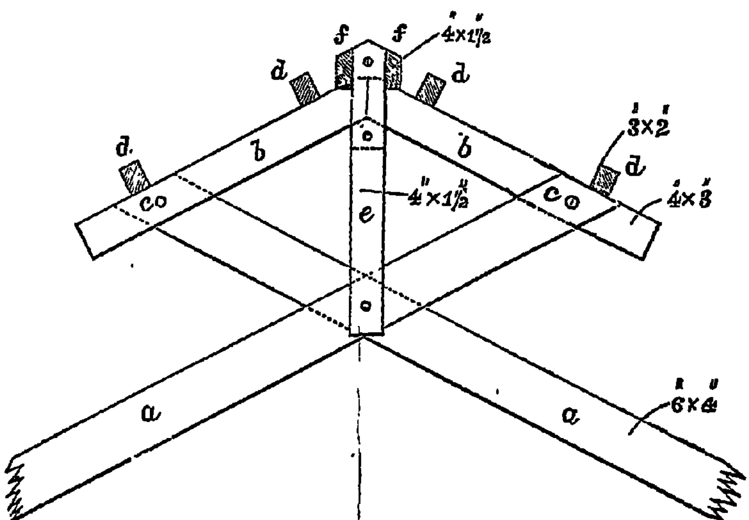


Fig. 117 is an elevation showing the arrangement of the roof timbers to provide ventilation along the ridge of a roof. a, a *are the principal rafters continued on beyond the ridge, so as to support the small rafters* b, b *which carry the ventilator ;* b, b *are small rafters which are notched and bolted at* c *on to the principal rafters ;* d, d *are the battens to which the roof materia is fastened ;* e *is a suspending piece (see Fig. 46, page 117) bolted to the principal rafters and to the small rafters ;* f, f *is the ridge piece in two parts, placed one on either side of the suspending pieces. The roof material is not shown. Scale* $=\frac{1}{10}$.

The roof may also be lined with planks nailed on to the underside of the rafters in order to keep out the heat or a wooden ceiling may be fastened to horizontal beams resting on the top of the walls of the rooms. Either of these additional linings, besides keeping the house cooler, deadens the sound of rain falling on the roof.

Another way of keeping houses roofed with corrugated iron cool is to place a light frame-work of bamboo on the sheets of

iron and fasten about two inches of good thatch on to it. Should the thatch be set on fire, it is believed that it will burn off without injuring the iron, provided the *maximum* thickness of thatch is only 2 inches. The noise caused by the falling of hail or rain, or by the contraction and expansion of iron, is almost entirely done away with, and the roof is not nearly so likely to leak. The roof in this case should not have a ridge ventilator. (*C. G. D. Fordyce.*)

In Quetta[1] wicker-work mats made of tamarisk twigs (*Tamaris* sp.) are nailed to the lower side of the rafters. These are then plastered and whitewashed and make a very cool ceiling. The spaces between the rafters, immediately above the outer walls, are closed with perforated zinc sheets, thus excluding bats and other vermin, but giving good ventilation.

§ 193. IRON SHEETING is commonly used for the roofs of store-rooms and out-houses in the hills, and sometimes even for dwelling-houses; it is cheaper and considerably lighter than corrugated iron, but not nearly so durable unless well painted. The sheets must be painted from time to time in order to protect them from the weather; if they are not painted or tarred on both sides they rust very quickly, and soon become worthless. The annual cost of keeping a roof made of sheet-iron in repair is considerable, and for this reason alone its use is not to be recommended for forest buildings in out-of-the-way localities. Sheet-iron is generally laid on boards when used for dwelling-houses.

FIG. 118.

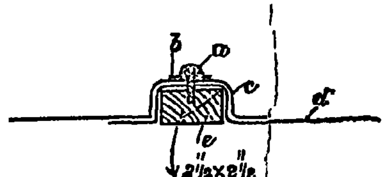


Figure 118 shows one method of fixing plain sheet-iron on to a roof. a *is the screw by which the iron is fastened on to the batten* (e); b *is the leaden washer*; c *and* d *are the sheets of iron which overlap bove the abattens. The battens run from the ridge to the eaves of the roof. Scale*=$\frac{1}{10}$.

[1] C. F. Elliott, Conservator of Forests, Punjab.

The sheets of iron are usually fastened with bolts or screws on to battens laid on the purlins, and the edges of the sheets are made to overlap 6 inches in both directions, as shown in Fig. 118, the battens running from the ridge to the eave of the roof. The roof may also be constructed in the way illustrated in Fig. 116, page 237. The screws used should be set in white lead, or else leaden washers should be used.

Figs. 119, 120, and 121 illustrate a modification of the Naini Tal pattern of sheet-iron roofing adopted by Mr. Leete, F.C.H., Assistant Conservator of Forests, which is much preferable though more complicated (as a machine for bending the iron sheets into rolls is necessary) than the method shown in Fig. 118.

In the ordinary Naini Tal pattern sheet-iron roof the ridge sheets (*q*) are not bent as shown in the above figures, but lie flat on the top of the rolls (*r*), and in consequence there is always a vertical space of 2 inches between it and the flat sheets (*s*, *s*) which constitute the roof, and rain is very liable to blow in through this space. If the ridge sheet is put on as shown in Figs. 119 and 120, this disadvantage is obviated. A full sheet split slightly at *x* (Fig. 119) to allow for the rolls may be used as a ridge piece. The ridge sheet is bent so as to fit a corresponding bend in the uppermost flat sheets of the roof (see Fig. 120). The latter is placed into the former before the ridge piece is placed in position. The clips *c*, *c* (Fig. 119) are screwed on to the planking, and are intended to hold down the sheets; after these clips have been screwed on the rolls are placed in position, and require no screws to keep them in place, but are kept from sliding off by a clip *d* fastened to the lower end. A couple of screws in each roll keep it quite as securely in position, and are much simpler, though when the roof is old may cause it to leak slightly.

FIG. 119.

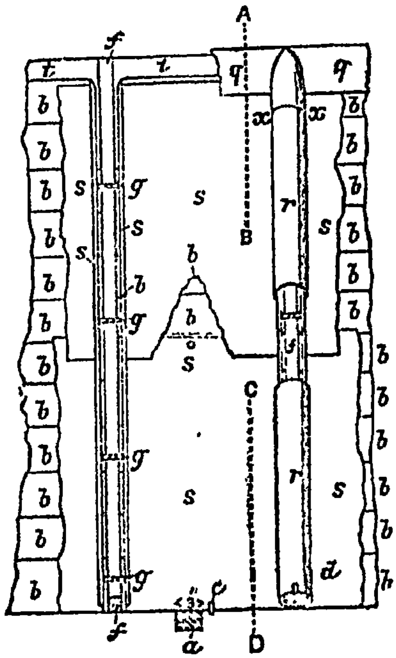


FIG. 120.

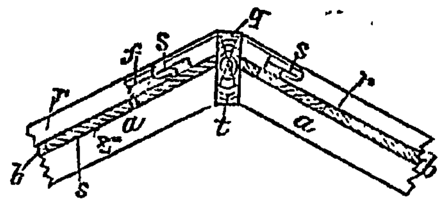


FIG. 121.

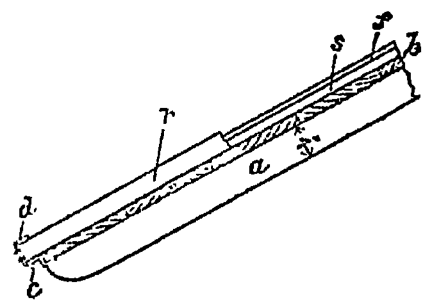


Fig. 119 is an elevation of the modified Naini Tal pattern of sheet-iron roofing. Figs. 120 and 121 are vertical cross-sections on the lines A B *and* C D, *respectively.* a *is a rafter in elevation;* b, b *the planking (in Figs. 120 and 121: the planking is in section and in Fig. 119 in elevation);* c, c *are clips which help to keep the sheets of iron in position;* d *is the clip which keeps the lower end of the roll in place;* f *is the batten in elevation in Fig. 119 and in longitudinal section in Figs. 120 and 121, over which the rolls are fitted;* s, s *are the sheets of iron, and are in elevation in Fig. 119 and in sectional elevation in Figs. 120 and 121;* q *is the ridge roll: it is in elevation in Fig. 119, and in section in Fig. 120;* r *is the roll which is slipped over the bent edges of the flat-iron sheets. It is in elevation in all the figures. The upturned edges of the flat sheets of iron are seen in the left portion of Fig. 119;* t *is the ridge piece, and is in elevation in Fig. 119, and in cross-section in Fig. 120. Scale=2 ft. to the inch. (Drawn by F. A. Leete.)*

The following table taken from Molesworth's pocket book of engineering formulæ (21st edition), page 39, shows the weights of the different thickness of sheet-iron :—

Birmingham wire gauge.	Thickness in inches.	Weight per 100 sq. ft.
No. 20	·035	140
No. 21	·032	128
No. 22	·028	112
No. 23	·025	100
No. 24	·022	88
No. 25	·020	80
No. 26	·018	72
No. 27	·016	64
No. 28	·014	55

§ 194. COMPARATIVE ADVANTAGES OF THE DIFFERENT ROOFING MATERIALS MENTIONED ABOVE, AS REGARDS WEIGHT, DURABILITY, COOLNESS, AND COST.—The cheapest and coolest of all roofing materials is *grass*, and this is in consequence the one most generally used for forest buildings in the plains of India. Its one great disadvantage is that it offers no resistance to fire. A thatched roof is not durable, and the grass covering has to be partially renewed every few years, according to the nature of the climate and the kind of grass used, while the entire grass covering must be renewed every four or five years. The thatch harbours insects and vermin generally. Bats are often very troublesome in thatched roofs, as they live in the space between the ceiling cloth and the grass itself. As vermin generally get into this space through the intervals between the thatch and the wall plates, which rest on the top of the walls, these spaces should be blocked up with wooden planks or fine wire gauze stretched on wooden frames fitted between the rafters immediately above the walls. Small holes should be bored in the planking to provide for ventilation. If properly laid and kept in good repair, the roof is fairly waterproof.

Terraced roofs are heavy and expensive in themselves, and further necessitate the construction of specially strong walls and beams of a larger size to support them; they are, however, very durable and keep the house cool. They may be used for

important forest buildings where coolness and durability are necessary. Terraced roofs have a further great advantage over thatched roofs in that they are fire-proof. Their costliness generally prohibits their use, as far as ordinary forest buildings are concerned. The use of terraced roofs is, as a rule, so far as forest buildings are concerned, limited to those parts of the plains of India where lime, bricks or tiles, and wood are cheap.

Tiled roofs are considerably heavier than thatched roofs, but are more fire-proof and much more durable. Their initial cost is greater, but as they require very few repairs, if properly constructed of good materials, the difference in total cost between them and thatched roofs is small, in districts where tiles are cheap. They may be used in the hotter portions of India where thatching grass is not abundant, or where, on account of its inflammability, it is considered inadvisable to use it. Tiled roofs, if well laid in mortar and constructed of good materials, are durable, cool, and waterproof; they are much lighter and cheaper than terraced roofs, and are more fire-proof and much more durable than thatched ones.

Galvanised corrugated iron forms a fairly cheap, light, and durable roof. It is more durable than thatch, shingles, or painted sheet-iron, and in many cases than tiles. Houses covered with corrugated or sheet-iron are hotter than those covered with thatch or tiles, or those which have a terraced roof, and in consequence these kinds of material are not as a rule suitable for dwelling-houses in the plains of India.

Corrugated or sheet-iron roofs may be made much cooler by the addition of a ventilator along the ridge (see page 238, Fig. 117), a ceiling of wood, and also by covering the outer surface of the roof with whitewash or white paint. Corrugated iron is largely used for the roofs of tea factories in Bengal, in the districts near the Himalayas, and in Assam, and also for railway stations in Northern India.

Sheet-iron is extensively used for houses in Naini Tal (North-West Himalayas), and for most of the rest-houses of the central

circle, North-West Provinces. A special machine has been devised for bending the sheets and rolls so as to construct a roof without holes in the sheets making themselves.

Shingles form a light and cheap roof, which is less inflammable than thatch. Shingle roofs are usually constructed in hilly districts where suitable wood is cheap and easily obtained where thatching grass is not available, and where the cost of carriage renders the use of corrugated or sheet-iron out of the question. Shingles, especially if painted when thoroughly dry, form a fairly durable, neat-looking roof. In Assam they have not been found to answer owing to extremes of climate, and are being replaced or covered over with corrugated iron sheets.

Sheet-iron may be used for unimportant structures and store-rooms; it forms a lighter roof than either shingles or corrugated iron, but its general use in out-of-the-way places cannot be recommended on account of its small durability, *unless frequently painted*. If the sheet-iron is not very carefully placed in position the roof will not be waterproof.

§195. CEILINGS.—Ceilings are sometimes added to a roof, in order to hide its untidy undersurface, to prevent the insects and vermin which live in it from falling into the rooms, or in order to form an additional protection against the rays of the sun.

Where the roof is made of thatch, it is very necessary to have a ceiling of some sort in order to keep the insects and vermin, which live under the roof, from gaining access to the rooms themselves; while in localities where the heat is very intense, a substantial ceiling adds very materially to the coolness of the house. Where the undersurface of the roof is untidy, a ceiling always improves the appearance of the rooms themselves.

When ceilings are constructed in order to add to the coolness of a house, they should be made of some substance, such as wood, which offers resistance to the passage of heat. When,

however, they are only added to keep out vermin or to improve the appearance of the rooms, they are commonly made of thin cotton material tightly stretched on a light wooden frame and whitewashed.

In India where forest houses rarely have a second storey, the ceiling is attached to the undersurface of the roof timbers themselves. Where there is an upper storey with a wooden floor, the ceiling is attached to special joists fastened to the bridging joists of the floor itself.

Where ceiling cloths are used, light wooden frames are usually attached to the roof timbers on a level with the top of the walls, and the cloth very tightly stretched is fastened to these and white or colourwashed. The great objection to ceiling cloths, in thatched houses especially, is that holes are eaten in them by the vermin which live in the roof; that they quickly become discoloured by them; and that they very soon become baggy, and then look far from neat. If ceiling cloths are adopted, precautions must be taken (see page 242, § 194) to effectually keep vermin out of the roof itself.

Ceiling cloths may, where the walls are low, be fixed on to the underside of the rafters themselves, or in roofs where a collar beam (see Fig. 123, page 248) is used; the frame carrying the cloth may be fastened to the collar beam and the lower portions of the rafters.

Wooden ceilings are in every way preferable to ceiling cloths, provided proper arrangements are made for ventilation; and though more expensive to put up, are much more durable, and need practically no repairs. Wooden ceilings can be made in many styles. The simplest consists of planks joined in any of the ways shown on page 129, Figures 54 to 58, nailed, or what is preferable screwed, to the undersurface of the rafters of the roof, or to a light frame-work fastened to the rafters themselves. Small battens beaded and moulded may be fastened on to the planks, so as to hide the joints between them if

better looking ceiling is desired. Many kinds of woods which cannot be used where they are in exposed positions will do very well for ceilings. A wooden ceiling may, like a ceiling cloth, be fastened on a level with the tops of the walls of the room, or to the lower side of the tie or collar beams (see page 248, Fig. 123) if such exists, so as to form a spacious chamber between it and the roof; or else may be fastened directly to the underside of the rafters.

Where economy is an object, the ceiling of the verandahs of thatched houses may be made out of the thinner portions of the flowering stems of *Sacharum sara (Sirkhi)* or other large grasses. If these are sorted and cut into lengths and fixed between battens to the rafters, they form a neat and fairly durable ceiling. (*A. G. Hobart-Hampden.*)

SECTION VII.—ROOF TRUSSES.

§ 196. The method of supporting flat roofs has already been considered under the head of terraced roofs (see page 207, § 171).

For pent or sloping roofs, the arrangement of the timbers which support the roof depends upon the span of the roof, *i.e.*, the horizontal distance between the points of support of the roof timbers and the weight of the roofing material, and upon the presence or absence of intermediate cross walls in the building which can support the *ridge piece* (see § 200, page 251) of the roof truss.

The arrangement of timbers which carry the roofing materials of a pent roof is called the *roof truss*. Where the roof is light and the span small, and partition walls are built at frequent intervals across the building (as in the case of a row of servants' houses) no special roof truss is necessary. A ridge piece will be placed along the top of the walls from one partition wall to the other; wall-plates will be placed on the top of the side walls; and if the width of the building is more than 20 feet, strong *purlins* (§ 200, page 251) may be laid from one partition wall to the other between the ridge-pole

and the wall-plates. The *rafters* and *battens* (§ 200, page 251) to which the roofing material is fastened should be laid on the wall-plates and purlins, and should be framed into the ridge piece. Where the span is less than 20 feet the *purlins* may be omitted, and the number of *rafters* increased sufficiently to bear the weight of the roof.

§ 197. COUPLE ROOF TRUSS.—The simplest form of roof truss is that shown in Fig. 122.

FIG. 122.

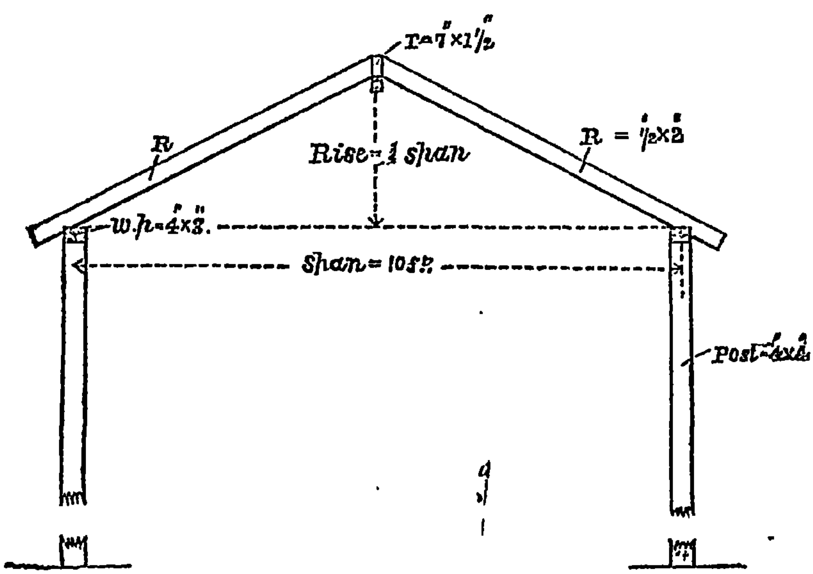


Fig. 122 shows a simple couple roof for a wooden house. r *is the ridge piece in section ;* R, R *rafters in elevation ;* w. p. *the wall-plate in section. The posts supporting the roof are seen in elevation. The distance between the rafters depends upon the weight of the roof to be supported. Scale* $=\frac{1}{20}$.

This kind of roof truss should only be used for light roofs of spans of less than 20 feet, and is suited for the construction of servants' houses, guards' huts, and stables. The ridge piece (r) should be supported by cross walls, or posts, at intervals of from 10 to 15 feet. The rafters (R) should be notched (see Part I,

page 112, Fig. 36) on to the wall-plates and may be butted against and nailed to the ridge piece, or else may rest on it. In a couple roof truss opposite feet of the rafters are not tied together, and nothing but the lateral stability of the supporting posts or walls prevents their spreading outwards under the weight of the roofs.

§ 189. COLLAR BEAM TRUSS.—In order to remedy this defect a *tie* or *collar* may be added (see Fig. 45, page 116). The collar beam may be fastened to the feet of the rafters when it is called a *tie-beam*, or may be notched and nailed to them at some distance above their lower ends, usually at about $\frac{1}{3}$ to $\frac{1}{2}$ the vertical height of the roof.

FIG. 123.

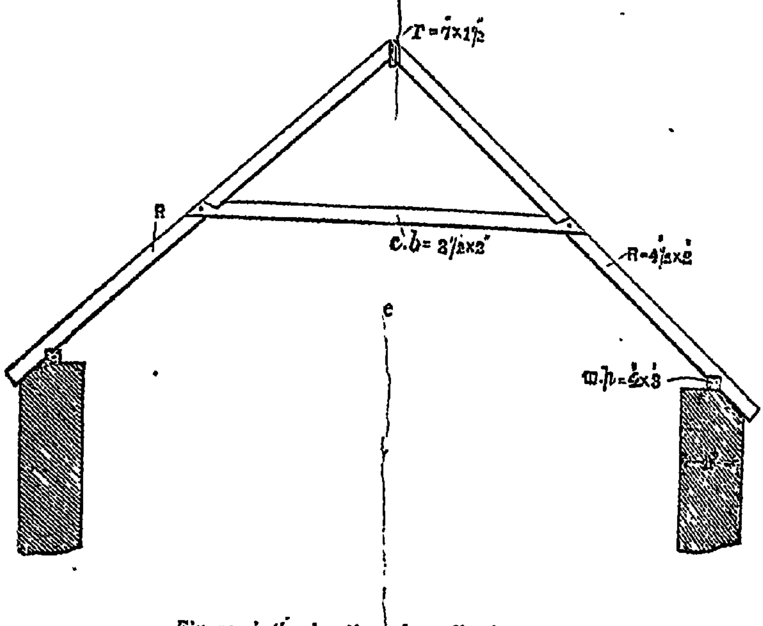


Fig. 123 is the elevation of a collar beam roof truss. r *is the ridge piece in section;* R, R *are the rafters;* w. p *is the wall-plate;* c b *is the collar beam, which is slightly notched into the rafter. The rafters are placed 1 foot apart and are nailed to the ridge piece. The walls shown are of masonry or brick-work. Scale 4 feet = 1 inch.*

In Fig. 123 the feet of the rafters (R) are notched on to the wall-plates (w. p.), and their upper ends are nailed to, or rest against, the ridge piece. The ridge piece is supported by the partition walls which divide the rooms of the building one from another. The collar beam (c) is slightly notched into and nailed on to the rafters, and thus prevents their ends from spreading. The collar beam should be notched into rafters as shown in Fig. 45, page 116. Comparatively slight wrought-iron tie-rods of round or hexagonal bar may be substituted for wooden collar beams.

If the walls give way, the rafter will probably break just below or at the notching on of the collar.

§ 199. KING POST TRUSS.—For spans of 20 feet and upwards the rafters should be supported near the centre of their length to obtain sufficient strength to carry the weight of the roof, unless very large scantlings are used.

Common rafters of moderate dimensions are employed, supported by longitudinal timbers, called *purlins*, running at right angles to them and resting in their turn on cross walls or, if such do not exist, on heavy framed trusses set up at intervals across the space to be roofed.

The simplest form of these independent trusses is the king post truss shown in Fig. 124, page 250.

It consists essentially of *tie-beam* (T) crossing the whole span, two *principal rafters* (P. R and P. R) parallel to the ordinary or *common* rafters (C. R), framed at their lower end into the ends of the tie-beam, and abutting at their upper ends against the head of the *king post* (K. P). The lower ends of the principal rafters are strapped to the tie-beam.

FIG. 124.

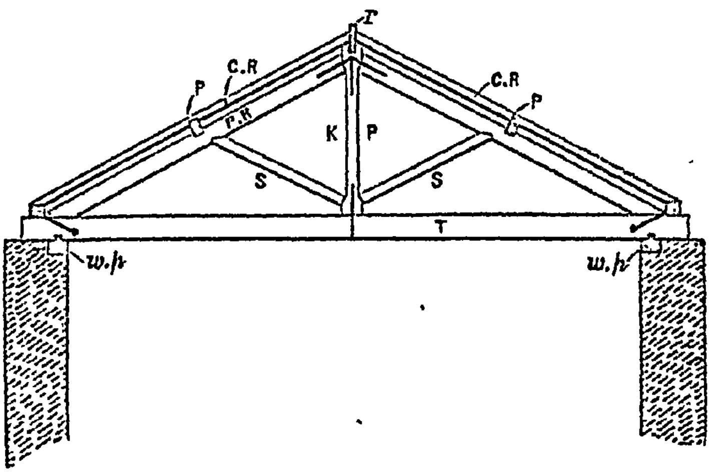


Figure 124 is an elevation of a king post truss showing its different parts. T *is the tie-beam ;* K P *the king post ;* S, S *the struts ;* P R *the principal rafter ;* C R *the common rafters ;* P *the purlins ;* r *the ridge piece ;* w. p *the wall-plates. Straps are shown joining the principal rafters to the tie-beam, the tie-beam to the king post, and the upper ends of the principal rafters to the head of the king post.—(From Building Construction.*[1])

The King Post supports the centre of the tie-beam by means of an iron strap and carries on its lower shoulders the small *struts* (S. S) which in their turn are framed into, and support at their upper ends, the centre of the principal rafters. The whole construction forms a rigid frame-work. From truss to truss are laid the *purlins* (P. P) on the principal rafters, near the points at which they are supported by the struts. Along the heads of the king post runs the *ridge piece* (R) ; and on the tops of the tie-beams just beyond the lower ends of the principal rafters, are nailed the wall-plates on which the feet of the common rafters rest.

The common rafters are then laid as may be required with their upper ends abutting against the ridge piece, their lower

[1] See foot-note on page 160.

ends fixed to the wall-plates, and their centres supported by the purlins.

The common rafters are sometimes omitted and the roof material is laid directly on the purlins. The details of the different joints used are given in Section IX, page 103, *et seq*.

King post trusses may be used for spans up to 30 feet; they are placed generally 10 feet apart, and are made sufficiently strong to carry the weight of the intermediate portions of the roof which they will be required to support.

§ 200. CONSTRUCTION OF A KING POST TRUSS.—The joints between the different scantlings of which the truss is composed may be strengthened with straps if necessary. The tie-beam is subjected to a tensile stress only if no ceiling is fixed to it. The centre of the tie-beam should be strapped to the king post. The king post should be made of the strongest wood available. The head of the king post should be enlarged if possible, so as to afford a bearing surface perpendicular to the direction of the pressure exerted on it by the principal rafters, and its foot similarly shaped to receive the struts. The top of the king post may be left square, or bevelled off as a bearing surface for the common rafters.

If it is difficult to get a single piece of wood of the required dimensions sufficiently long for the tie beam, two pieces of wood should be scarfed together as described on page 108, § 87.

The ridge piece is fitted into a groove, cut for its reception in the heads of the king posts.

The joints between the heads of the principal rafters and the king post should be left a litile open to allow for the settling of the roof (see page 115, Fig. 43).

The heads of the struts should be framed into the principal rafters so as to directly support the purlins, if this can be done without inclining the struts at a vary small angle to the horizon; the more upright the struts are placed the better able are they to resist the strain on them.

The struts should be tenoned into the principal rafters.

The principal rafters carry the purlins. The purlins are notched on to the principal rafters, so as to keep the latter in their proper position; they are sometimes supported by blocks of wood fastened to the rafters, in order to prevent their being themselves displaced.

The purlins should be in as long lengths as possible, and should be scarfed or fished where necessary; if scarfed, the scarf should rest on one of the king post trusses.

The ridge piece is a board from 1 to 2½ inches thick, against which the common rafters abut. It is sometimes omitted, and the rafters nailed to each other at the top instead.

The common rafters are bevelled at the upper end so as to abut against the ridge piece, and are nailed to it. They are notched on to the purlins, are always in one piece, are about 2 inches wide, and are usually placed 12 inches apart; if the dimensions of the common rafters are increased, the distance between them may be made greater. The eaves gutter (see page 276, § 211) is fastened to them. When a chimney passes through a roof the common rafter should be trimmed round it, in the same way as floor joists are trimmed round a fire-place (see page 195, § 157); the trimmers are placed at right angles to the common rafters, and the dimensions of the rafters on either side of the chimney should be increased proportionately to the increased weight which they will have to carry.

If the purlins are omitted, the common rafters should be placed on the principal rafters paralled to ridge piece, instead of at right angles to it, and should rest on the cross walls of the building. The battens supporting the roof material are then placed at right angles to the common rafters, and nailed on to them.

The following table, taken from "Building Construction,"[1] gives the dimensions of the scantlings for a king post truss. The truss being made of *(Pinus Sylvestris)* Baltic fir, which has about the same transverse strength as Morinda *(Abbies Webbi-*

[1] See foot-note on page 160.

ana), Toon *(Cedrela toona)* and Mango *(Mangifera indica)*, (see table on pages 90 and 91), and covered with countess slates (weight about 10 lbs. per square foot); the horizontal wind force being taken as 45 lbs. per square foot. The pitch of the roof being 30°, the trusses are placed 10 feet apart from centre to centre:—

Roofs without Ceilings.

Span. in feet.	Tie-beam.	Principal rafters.	King post.	Struts.	Purlins 10 feet bearing.	Common rafters.
	In inches.					
20	4½×3	5×3	3×2¾	3×3	5×7½	2×3½
22	4¾×3	5½×3	3×2¾	3½×3	5×7¾	2×3¾
24	4½×3½	5½×3½	3½×2¾	3½×3½	5×8	2×4
26	4¾×3½	5¾×3½	3½×2¾	4×3½	5×8¼	2×4¼
28	4½×4	5½×4	4×2¾	4×4	5×8½	2×4½
30	4¾×4	6×4	4×2¾	4½×4	5×8¾	2×4¾

If the span of the roof is 45°, add 1 inch to the depth of the common rafters, purlins, and struts, and ½ an inch to the depth of the principal rafters given above.

The joint between the tie-beam and the principal rafter should be placed over the supporting wall; if this is not done, the depth of the tie-beam should be increased by 2 inches.

§ 201. Iron Rails.—Worn-out iron and steel rails are now being extensively used by the railway authorities and others as a substitute for wooden beams in the construction of houses and sheds near railways where old rails can be obtained at a low rate, and suitable wood is not easily obtained, or when large weights have to be supported.

The rails may be bent while red hot into any required shape, and are fastened together by bolts and nuts or else by suitably shaped iron brackets ¼ inch thick.

Beams may be bolted on to the rails or fastened to them by iron brackets.

Rejected rails are used in the construction of trusses for supporting thatched, corrugated iron, and light-arched roofs, and also for terraced roofs of a small span.

If used instead of girders or beams for supporting an arched roof, or in any position where they are only supported at either end, they should be given a camber of 2½ or 3 inches, while the ends of the rails in the walls should be well backed to prevent their spreading.

SECTION VIII.—CALCULATION OF THE DIMENSIONS OF SCANTLINGS USED IN THE CONSTRUCTION OF ROOF TRUSSES AND IN SUPPORTING THE ROOFING MATERIALS USED.

§ 202. In Europe tables have been constructed giving the dimensions of the scantlings of the few kinds of wood in more common use in the construction of roof timbers, for the chief kinds of roofing materials, and for definite spans and different pitches of roofs. But in India, where the woods found locally are generally used for building construction; where the number of species of trees used is very considerable; where the number of buildings constructed of wood in any one locality (except in large towns) of any one species is small; and where the different properties of the trees are as yet imperfectly known, no such tables, which could be generally applied, have yet been drawn up. The quantity of any species of wood used, with the exception perhaps of Teak *(Tectona grandis)* and Sâl *(Shorea robusta)*, is not sufficient to render the construction of such tables a necessity. Consequently, it is usual, when the general design of the roof has been finally settled, to calculate the dimensions of the various timbers from the same formulæ, from which tables, similar to those above referred to, would have to be constructed.

The dimensions of any scantling may be determined if the following data is given:—

(1) The distance between the points of support of the scantling.

(2) The weight of the superstructure to be supported by the scantling.

(3) The area of superstructure which the scantling has to support.

If the dimensions of the scantling to be used are given, the distance between the scantlings can be similarly calculated.

The dimensions of the scantlings which directly support the roof material used are first calculated. Then the measurements of those immediately below these are determined, and the process continued until the sizes of all the scantlings used in the roof have been calculated. For example, in the case of a flat roof (see page 207, § 171), we should first calculate the dimensions of the small scantlings *(burgahs)* on which the roofing material rests directly, and then the size of the beams upon which the *burgahs* rest. In a pent roof we should begin with the battens, and end with the principal rafters and tie-beam of the roof truss if there is one (see Fig. 124, page 250).

The distance between the points of support of the scantling will be known when the design of the roof has been settled. The weight of the superstructure which each scantling has to support can be easily calculated when the nature of the superstructure and the area which the scantling has to support are known. The former quantity depends upon the material used in the construction of the roof proper and that used for any scantlings which it may also support. The area of the superstructure which is supported by any one scantling is clearly shown in Figs. 125 to 129, page 256, *et seq.* The determination of the dimensions of the roof timbers in the case of flat and pent roofs will be dealt with separately, in order to prevent any possibility of confusion.

§ 203. CALCULATION OF THE DIMENSIONS OF THE TIMBERS IN A FLAT ROOF.—In the case of a flat roof, the area of roof supported by any *burgah* is the shaded portion *a b c d* (Fig. 125); the points *a b c d* are midway between the *burgahs*. The *burgahs* are placed at equal intervals from each other, so that

the area of the superstructure, and consequently the weight that each one has to support, will be the same.

FIG. 125.

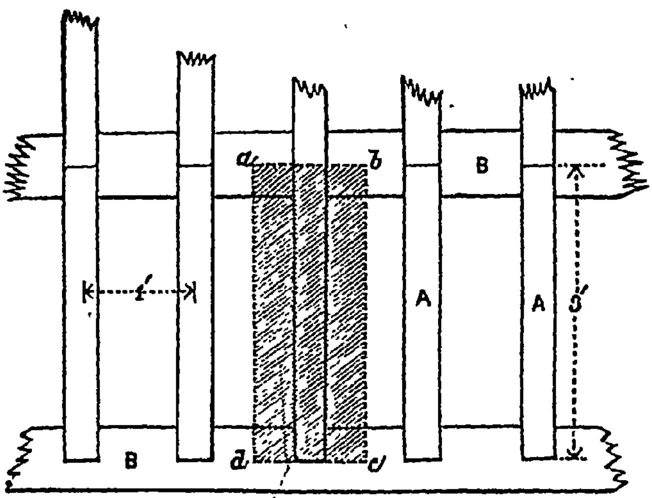


Figure 125 shows the area of roof supported by a burgah in a terraced roof. A, A *are burgahs placed 12 inches apart from centre to centre;* B, B *the beams which support the burgahs are placed 3 feet apart from centre to centre. The shaded portion* a b c d *is the portion of the roof supported by any one burgah. Scale 2 feet = 1 inch.*

The weight (W) which each *burgah* has to support is the weight of the roofing material on the area *a b c d.*

Figure 126 shows the area of pressure supported by one of the main beams of a flat roof. Each beam supports the weight of everything above it, *i. e.*, the weight of the *burgahs* as well as that of the roofing material.

FIG. 126.

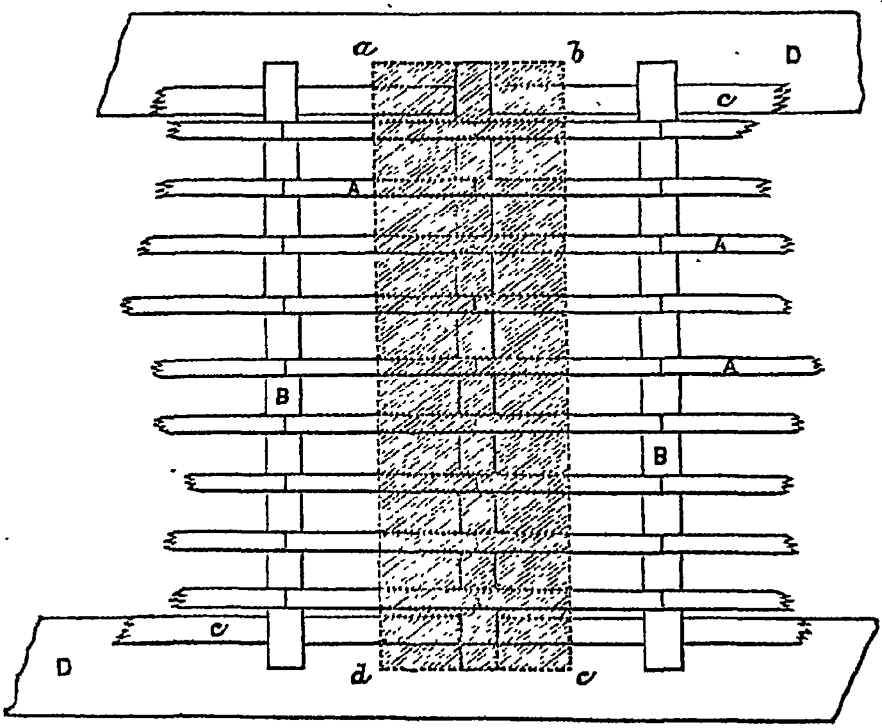


Figure 126 shows the area of pressure on a beam of a terraced roof. The shaded area a b c d *is supported by one beam.* A, A *are burgahs ;* B, B *are beams ;* C, C *are the wall-plates, and* D, D *walls. Scale 4 feet = 1 inch.*

Having thus found the data referred to in § 202, page 254, as necessary of the calculation of the dimensions of any scantlings, we may proceed to determine the actual dimension of the small scantlings (*burgahs*) which support the roofing material, and of the beams on which the *burgahs* rest.

This may be done by making use of the formula given in § 156, page 194, depending upon the amount of deflection of a beam supported at either end if the constant is known, or by adopting the formula derived from the co-efficient of transverse strength given below.

The weight which will break a *horizontal rectangular*

beam, supported at both ends and bearing a weight *equally distributed* along it is given by the formula—

$$W = \frac{2\,P.\,b\,d^2}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

This formula is obtained from formula [16] given on page 73 of Tredgold's "Carpentry" by Hurst, 4th edition, as here the weight is taken as equally distributed, while in Tredgold's formula the weight is taken as concentrated at the centre of the beam.

In the above formula:

L=length of the beam (between supports), in feet.

b=breadth of the beam, in inches.

d=depth of the beam, in inches.

P=co-efficient of transverse strength for the wood used, in lbs.

W=weight which would break the beam, in lbs.

In this formula L is known from the design of the roof: we want to find b and d.

The values of P for the more common Indian timbers are given in a tabular form on pages 90 and 91. The weight of the roofing material to be used should be found out experimentally in each case.

W depends upon the nature of the roofing material used.

The average weights of the more common materials used is given in the following table:—[1]

Material.	Weight in lbs. per 100 sq. feet.
Corrugated iron, 20 B. W. G.	224
" " 21 B. W. G.	205
" " 22 B. W. G.	185
" " 23 B. W. G.	165
" " 24 B. W. G.	150
" " 26 B. W. G.	112
Slates, ordinary	550-800
Thatch, 9 inches thick	650-1,000
Tiles	1,200-1,800
Zinc, $\frac{1}{32}$ inch thick	150
Sheet-iron, $\frac{1}{8}$ inch thick	500
Terraced roof, 8 inches thick	7,000

[1] Taken chiefly from "Building Construction," Part III, Materials (edition of 1889), page 288, and Part II (edition of 1891), page 56.

The weights of the more common woods has been given in the table on pages 90 and 91.

Besides the actual weight of the roofing materials, we should allow 25 to 50 lbs. per square foot extra for the pressure of the wind in the case of pent roofs, 3 lbs. for rain, and at high elevation 7 lbs. for snow.

This formula will give us the *breaking weight* of the scantling in question. As we wish, however, to find out the dimensions of the roof timbers strong enough to carry the roof, we must apply a *factor of safety* to the breaking weight W given by the equation (1).

This *factor of safety* is the number by which the *breaking weight* must be divided, in order to obtain the *safe* or *working load* which the scantling can bear.

In fixing a factor of safety we may have to distinguish between the *dead load, i. e.*, one which is added gradually and remains steady, such as the materials of which the structure is made, and the *live load, i. e.*, a load which is added suddenly, and is movable, such as a body in motion passing over a bridge, people walking over a floor. In the case of roof scantlings we have only to consider the effect of a dead load. Rankine's values of the factors of safety for metals, wood, and stone are as follows:—[1]

Material.	Dead load.	Live load.
Metals	3	6
Wood	4 to 5	8 to 10
Masonry . . .	4	8

The factor of safety in structures of stone should not be less than 8, to allow for variations in the strength of material as well as for other contingencies.

The factor of safety in various structures of carpentry vary from 4 to 14 and is on an average 10.

[1] Rankine's "Manual of Civil Engineering," pages 222, 361, 457, 15th edition, 1885.

A committee of the American International Association of Railway Superintendents of Bridges and Buildings in their report on "the strength of bridge and trestle timbers," October 16th, 1895, have recommended the adoption of the following factors of safety for wood under different kinds of stresses:—

In tension with and across the grain	10
Under compression with the grain	5
Under compression across the grain	4
Transverse rupture, extreme fibre stress	6
Shearing with and across the grain	4

Consequently, in order to find the dimensions of scantlings or beams which will carry a given load *with safety* we must apply the factor of safety of the material used to its breaking weight. Thus if F= the factor of safety of the material used then equation (1), page 258, becomes—

$$w = \frac{2\ P.\ b\ d^2}{F\ L} \qquad (2)$$

where w is the *safe load* which can be carried by a scantling of b inches broad and d inches deep, and L feet long.

In order then to find out the number of *burgahs* and beams of a given dimension, which will be required to support a flat roof, we may proceed in two ways. If the value of a is known, we may make use of the formula given on page 194, § 156, in connection with the determination of the dimensions of the floor joists; or we may make use of formula (2) given above: $w = \frac{2\ P.\ b\ d^2}{F\ L}$. This formula contains really 4 unknown quantities as b and d usually have a fixed ratio to each other, and thus become one unknown quantity. If any three of these unknown quantities are given, we can at once find the fourth. For example, suppose we are required to find the size of the *burgahs* of the roof shown in Fig. 125, page 256.

From the table given on page 258 we find that the weight of a square foot of terraced roofing 8 inches thick is 70 lbs.

The area of roof supported by one *burgah* is, from Fig. 125, 3 feet by 1 foot = 3 square feet: consequently the weight

which it will have to support is 3×70 lbs. $= 210$ lbs.; to this must be added the allowance for the weight of rain; 3 lbs. per square foot, or 9 lbs. in all; w of formula (2) is therefore equal to $210 + 9 = 219$ lbs.

Say the wood used for the *burgahs* and beams is Sâl *(Shorea robusta)*, we then find on reference to the table in Part I, page 91, that P=300—900 lbs.

Let us take P=600 lbs.

From Fig. 125, page 256, L=3 feet.

Consequently substituting these values in equation (2), page 262,

$$w = \frac{2\,P.\,b\,d^2}{F\,L}$$

we get—

$$219 = \frac{2 \times 600 \times b d^2}{5 \times 3}$$

since $w = 219$, F for wood under compression with the grain is 5 (see table on page 260) L = 3

$$\text{or} \quad b\,d^2 = \frac{210 \times 5 \times 3}{2 \times 600}$$

$$= 5{\cdot}47.$$

Now if we make the scantling as strong as possible (see Part I, page 66, § 47), then the relation which must exist between b and d is shown in the following equation :—

$$b : d :: \quad :: 0{\cdot}7 : 1{\cdot}0$$

$$\text{or } b = d \times 0{\cdot}7 \quad . \quad . \quad . \quad . \quad (3)$$

applying this relation to the example which is being worked out we get—

$$d^3 \times 0{\cdot}7 = 5{\cdot}47$$

$$\text{or } d^3 = \frac{5{\cdot}47}{0{\cdot}7} = 7{\cdot}81 \text{ nearly,}$$

$$\text{or } d = \sqrt[3]{7{\cdot}81}$$

$$= 1{\cdot}98 \text{ inches.}$$

$$b = 0{\cdot}7 \times d$$

$$= 0{\cdot}7 \times 1{\cdot}98$$

$$= 1{\cdot}4$$

so that if we make the *burgahs* 2½ inches deep and 2 inches wide, it will allow for any slight faults in the wood used.

If we use square battens then $b=d$, and we get by substitution in the equation—

$$b\,d^2 = 5{\cdot}47$$

$$\text{we get } d^3 = 5{\cdot}47$$

$$\text{or } d = 1{\cdot}76 \text{ inches,}$$

so that if we had *burgahs* 2½ inches square, they would be strong enough to carry the terraced roof in question.

The dimensions of the beams which support the *burgahs* can be similarly calculated. w, formula (2), page 260, in this case will be the weight of the roof supported plus the weight of the battens which carry it.

§ 204. If we have beams of a definite size (the distance between the *burgahs* usually depends on the size of the tiles or bricks used in the construction of the roof), and wish to know how many placed at equal distances will be required to support the roof, we should proceed as follows:—Calculate the area of the roof and find out its total weight, including the *burgahs*. Add to this the allowances for rain and snow. There is practically no wind pressure on a flat roof. This will give us the weight which all the beams have to carry. Let this = W. Then if the beams are placed equidistantly, each will have to support the same weight.

By substituting in formula (2), page 260, the values of P, b, h, and L, we find w, the safe load which one of the available beams of the kind of wood used can carry. Then if we divide the total weight to be supported (W), by w, we get the number of beams necessary to support the roof under consideration.

§ 205. SLOPING ROOFS.—In the case of a sloping roof surface we have to take another factor into consideration, *viz.*, the angle which the sloping surface, and consequently the rafters which support it, make with the horizon, as this angle affects

the breaking strain of the scantlings which are inclined to the horizon.

The relation between the transverse strength of beams on a slope to those which are horizontal is given in the following equation :—

$$P S = P' L. \quad \ldots\ldots\ldots\ldots \quad (4)$$

where

P = the breaking weight for a horizontal beam,

L = the horizontal distance between the ends of the beam in feet,

S = the distance measured along the slanting beam in feet,

P' = the breaking strain of a similar beam in a slanting position ;

or, in other words, P' is obtained by multiplying the breaking weight on a similar horizontal beam by the secant of the angle which the slanting beam makes with the horizontal plane.

The co-efficient of transverse strength (P) for horizontal beams is given in the table on pages 90 and 91, and consequently the breaking strain for any beam on the slant can be at once determined by substituting the tabular value of P in the equation given above.

In a pent or sloping roof some of the roof timbers are horizontal and others are inclined to the horizon. The weight supported by the horizontal members depends upon the area supported by each member, and has already been shown diagrammatically in Figs. 125 and 126, pages 256 and 257.

In the case of a pent roof the area of roof supported by any one batten placed horizontally is the shaded portion *a b c d*. Figure 127, page 264, *a*, *b*, *c*, *d* are on the rafters, and midway between the battens.

FIG. 127.

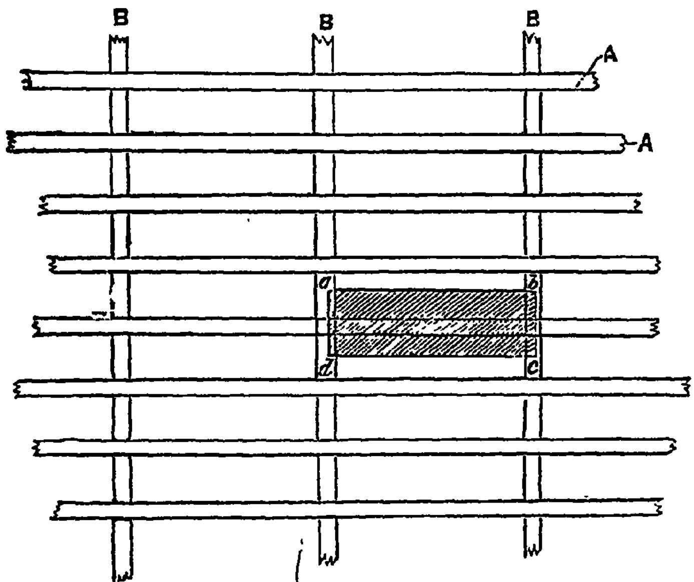


Figure 127 shows the area of roof supported by a batten on a pent roof. The shaded area a b c d *is supported by one batten.* A, A *are the battens;* B, B *the common rafters. Scale 4 feet = 1 inch.*

The area of a roof supported by a common rafter, purlin, or principal rafter may be determined similarly. In the case of a hip roof the last truss should be stronger than the others, as it will have to bear half the weight between itself and the next truss, as well as half of that of the roof supported by the hip rafters, as is shown diagrammatically in Fig. 128.

FIG. 128.

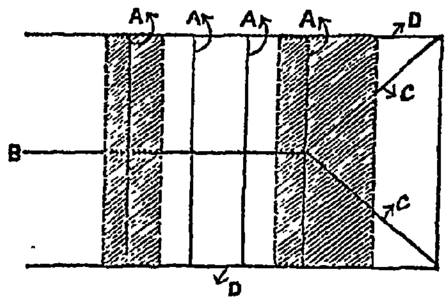


Figure 128 is a diagram showing the area of pressure on the trusses of a hipped roof. A, A, A *represent roof trusses;* B *is the ridge piece;* C, C *are the hip rafters;* D, D *the eaves of the roof. The shaded areas show the pressure on a truss in the middle of the roof, and on the truss on which the hip rafters rest.*

Each hip rafter supports the area shaded in Fig. 129.

FIG. 129.

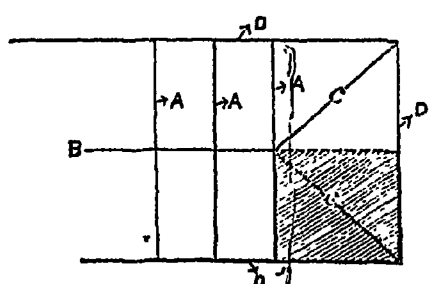


Figure 129 is a diagram showing the area of pressure on a hip rafter; the letters used are the same as in Fig. 128.

§ 206. The dimensions of all the horizontal members of a pent roof are calculated in the same way as the dimensions of the *burgahs* and beams of a flat are determined (see §§ 203 and 204, pages 256 to 262). As regards those scantlings which are inclined to the horizon, P, the breaking strain or co-efficient of transverse strength of the wood used is given in the table on pages 90 and 91, and P′ is from the equation (4), page 263

$$= \frac{P\,S}{L} \quad . \quad . \quad . \quad (5)$$

where P is the breaking strain for the wood used, S the distance between the points of support of the beam, and L the horizontal equivalent of this distance.

Consequently the dimensions of all the horizontal members of a pent roof can be determined from equation (2), page 260.

$$w = \frac{2P.b\,d^2}{F\,L}$$

and those of all slanting members of the roof timbers by using the formula—

$$w = \frac{2P'\,b\,d^2}{F\,L}. \quad . \quad . \quad . \quad (6)$$

Where $P' = \frac{P.S}{L}$., as has been stated in equation (5) given above.

If the distance between the battens is given, then we have to calculate their dimensions, and this will be done in exactly the same way as for the *burgahs* of a flat roof (see page 255, *et seq.*). If, however, the dimensions of the battens are given, we shall have to determine the number of battens which will be necessary if placed at equal intervals from each other. The actual distance between the battens will be known as soon as the dimensions of the roof are known; and these will be determined by the design of the building.

To take a numerical example, suppose we wish to calculate the number of Sâl (*Shorea robusta*) battens, 3 inches wide and 2

inches deep, required to support a tiled roof, the battens being supported on rafters placed at intervals of 6 feet, the weight of the tiles being 18 lbs. per square foot, and the distance from ridge to eave of the roof being 20 feet. The value of P for sâl may be taken as 700 lbs. (see table on pages 90 and 91). The weight of a square foot of roof surface is—

	lbs.
Weight of tiles per square foot	18
Allowance for wind	30
Allowance for rain	3
Total pressure per square foot of roof surface	51

The area of the roof between two consecutive rafters to be supported by the battens is $6 \times 20 = 120$ square feet, so that the total weight to be supported by the battens is $51 \times 120 =$ 6,120 lbs.

The safe load which can be supported by a batten is given by formula (2), page 260—

$$w = \frac{2P.b\,d^2}{F\,L}$$

$$\text{Here } P = 600,\ b = 3,\ d = 2,\ L = 6$$

$$\therefore\ W = \frac{2 \times 600 \times 3 \times 4}{5 \cdot 6},$$

or 480 lbs.

Consequently the number of battens required will be—

$$\frac{6120}{480} = 12\tfrac{3}{4}, \text{ or, say, } 13$$

distributed equally over the roof from ridge to eave (a distance of 20 feet).

By decreasing L, the distance between the points of support of the battens, or by increasing their dimensions, we can materially decrease the number of battens used.

The number of common rafters and other parts of the roof truss can be calculated similarly, remembering that if the scantlings are in a slanting position, we must use formula (6), page 266, instead of formula (2), page 260.

If the number of the battens or other scantlings are given, their dimensions can be calculated separately. Similarly, if we have battens or other scantlings of given dimensions, we can calculate the distance between them in order to support the weight of the roof with safety.

SECTION IX.—CHIMNEYS AND FIRE-PLACES.

§ **207.** A *chimney* is a structure which conveys the smoke and the other products of combustion from the fire-place into the open air. The actual passage through which the smoke, etc., passes is called the *flue*.

The *fire-place* is the structure upon or in which the wood or other material to be burnt is placed.

Every fire-place should have a separate flue. If two fire-places have a common flue, and a fire be lit in only one of them, it will either draw in air from the other fire-place and in consequence smoke, or its own smoke will find its way into the room in which the other fire-place is situated.

§ **208.** Flues are usually curved sufficiently to prevent rain beating vertically down on to the fire, and to stop down-draughts of cold air. The curve should be sufficient to prevent daylight being seen when looking up the flue from the fire-place. If the flue is not curved, the chimney must be provided with a cap to prevent the rain beating directly on the fire.

The lower end of the flue which is immediately above the fire-place is known as the *throat* of the chimney (see Figs. 130 and 131, page 270). The opening above the fire-place itself is contracted gradually so as to form this aperture. This is done

by making each course project about $1\frac{1}{8}$ inches over the last until the opening narrowed to the required dimensions.

The throat of the flue should always be over the centre of the fire-place.

Considerable difference of opinion exists as to the dimensions and shape of the flue of a chimney. Some engineers find that it is advantageous to make the *throat* smaller in area than the rest of the flue in order to prevent the chimney from smoking; others find that a contracted throat is not necessary and advocate the flue being kept the same size and shape throughout its entire length. Others, again, find that the chimney draws better if the throat is made long and narrow, but of the same superficial area as the rest of the flue. The greatest length in this case should be parallel to the surface of the wall. The flue above the throat curves gradually to the centre of the wall, and is carried up through the centre of the wall well above the roof. A high chimney is always less liable to smoke than a short one, as in the former case a better draft is obtained. In order to ensure the chimney drawing well, the superficial area of the flue is usually not less than 144 square inches, but should not be larger than is necessary to take off the products of combustion of the fire. The flue of a chimney should be made as the building rises; it should have no irregularities, such as projecting bricks, stones, lumps of mortar, etc., sticking out in it, and should be plastered very carefully throughout its whole length.

The construction of a fire-place and flue is shown in Figs. 130, 131 and 132, which represent th details of the fire-place and chimneys in the new kutchei buildings at Naini Tal, and were designed by Mr. F. O. Oertel, Public Works Department.

FIG 130.

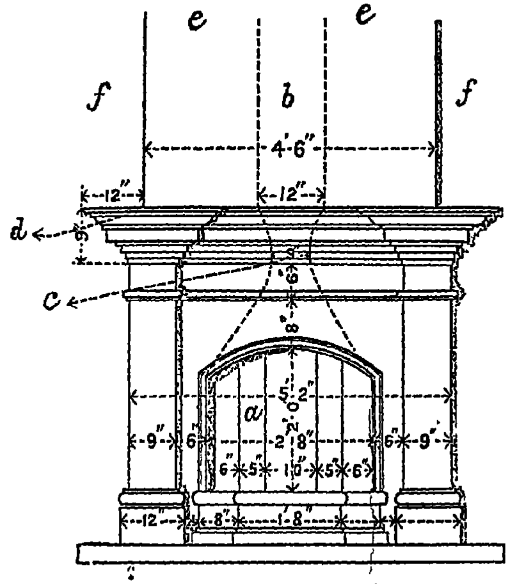


FIG. 131.

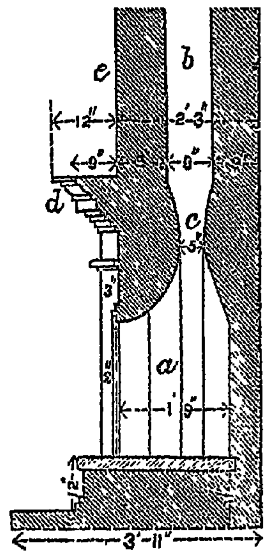


FIG. 132.

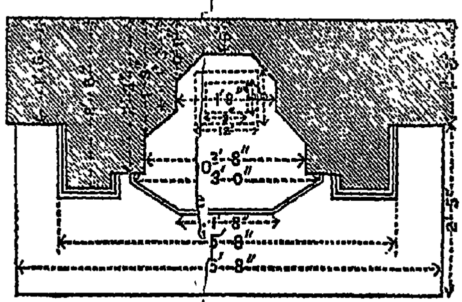


Fig. 130 is the elevation of part of a chimney. a *is the fire-place ;* b *is the flue (shown in dotted lines) ; c the throat of the chimney ;* d *the mantle-piece ;* e *the chimney breast ; and f the wall of the room.*

Fig. 132 is the plan of the fire-place, and the pillars which project out into the room and support the mantle-piece.

Fig. 131 is a longitudinal section through the fire-palce and flue showing how the opening above the fire-place is contracted to form the throat of the chimney ; letters as in Figure 130. (F. O. Oertel.)

Figs. 133 to 136 show the construction of the chimneys and fire-places of the new students' quarters at the Imperial Forest School, Dehra Dun.

FIG. 133.

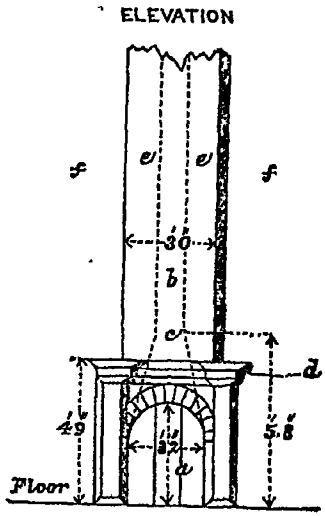


FIG. 135.

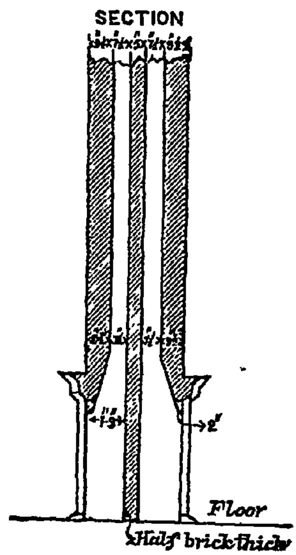


FIG. 134.

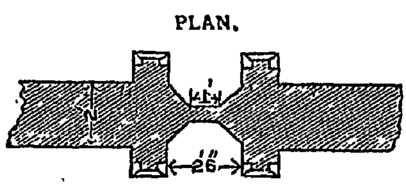


FIG. 136.

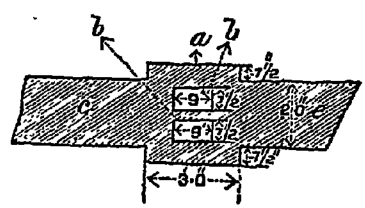


Fig. 133 is the elevation of part of a chimney, a *is the fire-place;* b *the flue (shown in dotted lines);* c *the throat of the chimney;* d *the mantle-piece;* e *the chimney breast; and* f *the wall of the room.*

Fig. 134 shows a plan of the two fire-places back to back, and the way in which the pillars which support the mantle-piece project out into the room.

Fig. 135 is a longitudinal section through the chimneys, showing how the space above the fire-place narrows up into the flues, and how the flue of each chimney is kept perfectly distinct.

Fig. 136 is a section at the throat of the chimneys; at a height of 23 feet above the floor the flues are 12" × 7½" in section. a *is the chimney breast;* b, b *the flues;* c, c *the wall of the room.*

These drawings have been made from the chimneys of the new students' quarters at the Imperial Forest School, Dehra Dun. Scale 6 feet=1 inch. Drawn by U. N. Kanjilal.

The air warmed by the fire passes up through the flue, and drawing the smoke with it, passes out at the top of the chimney, and in so doing draws more cold air up through the fire, thus causing it to burn freely.

The flue should not be larger than is necessary to carry off the heated air and smoke; if too large, the chimney will smoke (*i.e.*, the smoke will come out into the room instead of going up the chimney) when the wind blows from certain directions. The actual size of the flue varies with the size of the fire required, and the consequent volume of smoke produced. A flue 14 by 9 inches is sufficient for small fire-places, and one 14 inches square for all ordinary sized ones. The smaller the section of the flue and the greater its height, the more rapid will be the *draught* (the rush of heated air up the chimney), and the less likely will be the chimney to smoke, provided the flue is sufficiently large to carry off the smoke produced by the fire.

The inside of the flues should be made as smooth as possible and should be plastered with mortar consisting of one part of lime and three of cow-dung; this mixture forms a tough lining with a smooth surface, which does not crack so easily as ordinary plaster does.

Flues may be constructed around wooden frames made the exact size of the flue, and by this means its shape may be accurately formed and easily preserved. These frames are usually 3 or 4 feet long and are pulled up as the walls which contain the flue rise. Such frames are most useful in the case of masonry walls and are in that case usually circular in section.

The direction of the flue should be changed by gradual curves, and should contain no sharp angles (less than 135°) where soot can accumulate and cause the chimney to smoke.

The walls in the neighbourhood of chimneys should be carefully built, as should also the partition walls between the flues of different fire-places.

The chimney-stack should, if possible, be placed on the ridge of the roof; if placed on a sloping surface it will leak sooner or later, unless special precautions are taken.

If the interior walls are thin, their width has sometimes to be increased around the flue of the chimney, as shown in Fig. 136, page 271.

Great care should be taken that the ends of beams are not built into the chimneys. The ends of all beams and scantlings in the vicinity of chimneys must be most carefully trimmed around them.

The portion of the chimney above the roof known as the *stack* is generally made smaller than that below it; the slope of the upper surface of the ledge thus formed around the chimney should be the same as that of the roof itself. The top of this ledge should be on a level with the top of the rafters, so that the battens may be trimmed round it.

The chimney-stack should project well above the upper surface of the roof of the house. The upper end of a chimney is often protected from the weather by a cap of brick or stone; openings being left at the sides for the escape of the smoke.

Pieces of wire-netting placed over these openings will prevent birds from building their nests in the flues of the chimney and yet will not materially interfere with the egress of the smoke.

Figs. 137, 138 and 139, showing the construction of a chimney-cap designed to prevent the escape of sparks, and especially suitable for thatched buildings, are reduced from drawing in the Military Works Hand-book of Specifications.

FIG. 137.

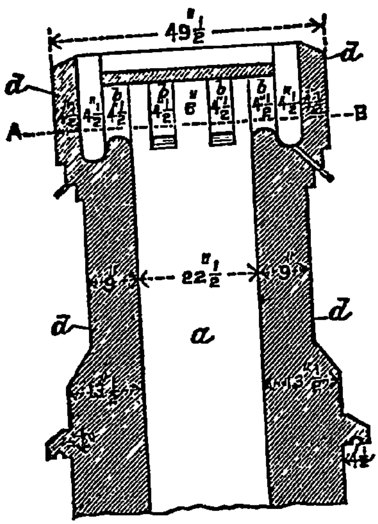


FIG. 138.

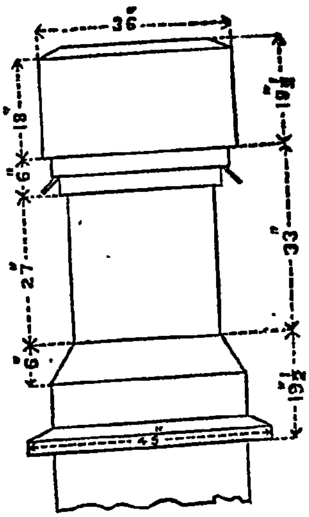


FIG. 139.

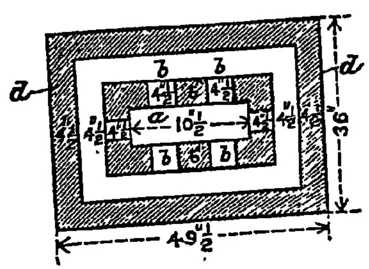


Fig. 137 is a vertical section of the chimney top, shown in elevation in Fig. 138 and in cross-section in Fig. 139. a, a is the brick-work (inside view of the flue) in elevation; d, d is the brick-work of the chimney in section; b, b are openings leading from the inside of the flue into the open trough, by which the smoke escapes; pipes to take of the rain which falls into the open trough are added; a stone slab 2 inches thick which is placed (not set in mortar) over the top of the flue, and prevents rain beating down the chimney.

Fig. 139 is a cross-section on the line A B. The same letters are used in all three figures. Scale 4 feet = 1 inch.

§ **209.** Care must be taken to prevent the occurrence of a leak where the chimney passes through the root, especially in the case

of sloping surfaces of thatched, corrugated iron, or tiled roofs. In the case of tiled or corrugated iron roofs, a layer of plaster may be put on the chimney after the roofing material has been placed in position so as to cover a portion of them, and to unite them to the chimney itself in such a manner as to prevent rain running down the sides of the chimney into the house. For thatched houses zinc or tin plates, bent to form a gutter, placed around the chimney, with one end embedded in the plaster of the chimney, and the lower end placed between the upper and second layers of thatch for about 2 feet all round the chimney, will prevent the roof from leaking.

§ 210. *Fire-places.*—Fire-places generally require more depth than can be provided for them in the thickness of the wall, and if this is the case, the portion of the wall which contains the fire-place must be made thicker. It may also be necessary in the case of thin interior walls to thicken them, so that they may contain the flue or flues of the chimney safely. This is especially the case when two fire-places are placed back to back. The projections of the wall, made for this purpose, are called *chimney breasts.* A chimney breast usually projects into the room, but if the chimney is on an outside wall, the projection may be made on the back of the wall instead.

The width necessary for the chimney breast can be determined by drawing the plan of the fire-place and flue or flues and allowing 9 inches (or the length of one brick) of wall outside the flue and 4½ inches (or half a brick) for the partition wall between them. If the fire-places are built back to back, the projection in each room will be similar in shape. The chimney-breasts should have good foundations. The upper part of the fire-place is narrowed so as to form the *throat* of the flue (as mentioned on page 268); this is done by making each course project about one inch beyond the one below until the dimensions of the flue are reached; the exact amount which each course will project will depend upon the curve to be given to the throat. The throat should be over the centre of the fire-place.

The opening of the fire-place above the grate should be constructed so that all the air which is drawn up through the flue must pass near the fire and be warmed by it.

Where wood is used as fuel, a small platform of masonry should be built in the fire-place, on which the wood is placed. The wood is laid on the platform, and the air passing up through the former creates a draught up the chimney.

In cold climates the sides of the fire-place may be splayed outwards so as to throw more heat out into the room.

Smoky chimneys may sometimes be cured by cutting a smoke lick, *i.e.*, a narrow groove up the back of the fire-place. It is essential that this groove should run up the chimney to a point above the height of the fire-place opening, otherwise the draught will carry the smoke up the groove, but will release it again before it has been safely conveyed into the flue. (*A. G. Hobart-Hampden.*)

The draught of a chimney may be increased by blocking up the upper part of the opening for the fire-place temporarily with a sheet of iron. Two holes should be pierced near the upper side of the sheet, and these should fit on to two nails driven into the wall in suitable positions. The sheet can be removed as soon as the fire burns up.

Hearth-stones.—Where the floor is made of wood, flat stones or slabs of concrete, should be placed immediately in front of the fire-place, so as to catch whatever inflammable materials fall out on to the floor.

SECTION X.—DRAINAGE AND LIGHTNING CONDUCTORS.

§ 211. The rain which falls on a roof may be carried off either by (1) fixing a gutter to its eaves, or (2) by making an open drain in the ground where the drip of the roof would fall.

Gutters may be constructed of two pieces of wood nailed together so as to form a V-shaped trough and lined with painted sheet iron or zinc if practicable; if they are made of

wood only they are not durable, and unless kept constantly wet soon begin to leak; and should only be used as a temporary measure.

Good durable gutters, semi-circular in section, are made of zinc, and also of galvanized iron in lengths of 6 feet. These may rest on iron staples fastened to the rafters, so as to catch the rain-water which falls on the roof. The different lengths of guttering should overlap each other for about 6 inches, and may be soldered together or else set in white lead. The gutter should lead into vertical pipes, which conduct the rain-water falling on the roof into drains dug in the ground lined with masonry or brick-work, made to carry it away from the foundations of the building. If these drains are covered ones, precautions must be taken to prevent their getting blocked up with leaves and other foreign matter. The lower end of the vertical pipe leading the water from the roof should empty into a small open reservoir connected with the covered drain, and an iron grating should be fitted into the mouth of the drain in order to prevent the entrance into it of leaves, etc., which would eventually block it up.

The upper portions of the vertical pipes, which are usually made of zinc, are funnel-shaped, and should be furnished with perforated zinc plates, placed at the top of the funnel, to prevent the pipes being blocked with leaves, etc. All the water which falls on the roof surfaces passes through the funnels into the vertical pipes. These pipes are usually circular in section and 3 or 4 inches in diameter.

When drains are made in the ground to carry off the water which falls on the roof in the absence of gutters along the eaves, they are usually open ones, as these can be more easily kept clear than closed ones can, and are made either square or rectangular in section; the sides and bases of such drains should be lined with thin slabs of stone set in mortar, and faced with a thin layer of Portland cement to render them water-tight, or be made of masonry or brick-work.

The object of the drains or gutter is to prevent the water

which falls on the roof from soaking into and so weakening the foundations of the building, and also to prevent the house from becoming insanitary.

§ 212. LIGHTNING CONDUCTORS.[1]—All buildings which from their height or exposed position are likely to be struck by *lightning* should be provided with lightning *conductors*.

Lightning is a discharge of atmospheric electricity accompanied by a vivid flash of light, while the thunder which accompanies it is the sound produced by the electricity in passing rapidly through the air.

A *conductor* is a substance which forms a medium for the transmission of some other substance or fluid. The best conductors for electricity are the metals, and among the more common of these the best are copper and iron.

If lightning is impeded by meeting a non-conducting surface, such as stone, wood or grass, the resistance offered to its passage by the non-conductor causes heat to be generated, generally in sufficient quantities as to burn or otherwise destroy the resisting body. If the resisting body is not inflammable the electrical discharge will often cause it to split and fall down. Consequently it is of the greatest importance to furnish buildings, which are non-conducting bodies, with a conducting substance which will lead the electrical discharge away from the building, rapidly, and without offering any resistance, to the earth, where it unites with the electricity in the earth and is rendered harmless.

Lightning passes chiefly along the surface of such mediums as are conductors of electricity.

A lightning conductor will afford protection over an imaginary cone having the point of the conductor for its apex and a base on the ground, the radius of which is equal to twice the height of the conductor above the ground. Everything within this imaginary conical surface is protected from lightning by

[1] R. S. Mann, M.I., F.R.C.S., F.R.A.S., in "Science for All," and Molesworth *p. cit.*, pages 363 and 364.

the conductor, or, in other words, the lightning will be attracted by the couductor and will pass to it rather than strike any other less conducting material within that space, and if the lower end of this conductor is given a good outlet into the ground, the lightning will pass along the conductor without doing any harm to the building. Faulty earth contact is undoubtedly the cause of many failures in lightning conductors.

Lightning conductors should, where practicable, be made of copper, as that metal conducts electricity very readily. They are usually made in the form of bands of 3 to $3\frac{1}{2}$ iuches wide and $\frac{1}{8}$ inch thick, or else in the form of a tube from 12 to 2 inches in diameter and $\frac{1}{8}$ of an inch thick.

If iron be used instead of copper the band should, on account of the smaller conducting power of iron, have six times as large a surface area. Plain sheet iron, 1 foot wide and $\frac{1}{16}$ of an inch thick, may be substituted for the copper band referred to above.

All metal water-pipes should be connected with the conductor where practicable.

The lightning conductor should be carried from the highest points of a building to the ground, without diminution in size, and should be connected with the more prominent lines of the building, such as the ridges, hips, and eaves of the roof. All metal surfaces should be connected by copper plates to the conducting system.

The upper end of the conductor should terminate in a solid rod of copper, which should project about 5 feet into the air from one or more of the highest points of the building; the tips of the rods should be *pointed*; as a point or cluster of points allows the electricity to flow off easily, and so diminishes the striking power in a storm cloud. Moreover, in this case the electricity escapes as a gentle stream instead of an abrupt spark. If lengths of conductors have to be connected, they must be riveted together closely, or so bound together that moisture shall not enter between the surfaces in contact, which should be clean and should overlap by several inches. The lower portion of the

copper band should be led into damp porous soil (moist earth being a better conductor than dry earth), and its surface should be enlarged where it enters the ground so as to allow of the free escape of the electricity. A conductor without a sufficient outlet is very dangerous. The conductor may be led into a trench 18 to 24 inches deep and 30 feet long, ending in a pit; the trench should be given a down gradient of 1 in 10. The end of the copper band should be fastened to a copper plate about 1½ feet square. The trenches and pit should be filled with charcoal or coal ashes, and covered with gravel or earth. It is very necessary that the lower end of the conductor should be taken well away from the foundations of the building.

SECTION XI.—ESTIMATES, PLANS, WORKING DRAWINGS, AND SPECIFICATIONS.

§ **213.** Before commencing the construction of any building or other engineering work it is necessary to determine the cost of its construction. This is especially necessary in the case of works constructed by Government, since the amount of money available annually for expenditure is previously fixed.

The estimate of the cost of construction should consist of a report, a specification, a detailed calculation of the measurements and volume of materials required, and an abstract showing the total estimated cost of each description of work separately, and should be accompanied by detailed drawings (*plans*) of the construction.

If the estimated cost is greater than the sum of money available, the estimate must be reconsidered and reduced, either by decreasing the dimensions of the building, etc., or by changing the nature of some of the materials of which it was to be made in order to reduce its cost to the amount available, or the construction of the building must be postponed till funds are provided.

The *heading* of the report should clearly specify the nature

of the work to be done, and its locality. In the case of Government works, the authority (if any is necessary) on which the estimate has been framed should be quoted, and reference to all the important correspondence on the subject should be made.

The *report* should state briefly the object to be gained by the execution of the work, discussing the reasons for the adoption of the designs submitted, and explaining such points as may be considered necessary. Full details regarding the site and the nature of the foundations must also be given.

In the case of a building the dimensions of all scantlings used, and the distance apart and size of the roof timbers should be given and justified. The system of drainage adopted should be discussed if necessary.

The *specification* should show clearly, and as briefly as possible, the details of the work, the manner in which it is to be executed, and the nature of the materials to be used.

The *plans* will show the size and shape of the entire structure, and such detail of parts as is necessary for the proper construction of the work.

The detail of the measurements will be taken off the plans and the volume of materials required calculated from them.

The *abstract of cost.* This statement shows the total cost of each kind of work separately. It should clearly show whether the rates given are for labour only or include the cost and collection of materials. If the rate given is for labour only, the cost and carriage of materials should be shown separately; 5 per cent. of the total cost is added for contingencies, but need not necessarily be spent. The different parts of the estimate will now be considered in detail.

§ 214. PLANS.—After the design of a building (bridge, or structure of any kind) has been determined, the next thing to be done is to prepare a series of drawings made to scale showing the size, shape, and dimensions of the various parts of the structure, as well as, so far as can be shown by conventional signs, the materials of which it is to be built.

These drawings constitute the *plans* of the building; the number of drawings required depends upon the simplicity and symmetry of the building to be made; a small, simple symmetrical building will require fewer drawings than a large, complicated, and unsymmetrical one. The building is constructed from the plans, so they should consequently afford a thorough and complete guide to the method of construction to be adopted in every part of the building.

The drawings should, in any case, be sufficient to show the construction of *every part* of the building, so that the builder who is given the drawings may be able to form a structure representing in every detail the drawing. Nothing must be left to the imagination. If any part of the drawings is incomplete, the building may be wrongly constructed.

Besides being drawn to scale, all parts of the drawing should be most carefully *dimensioned*, the measurements of the different parts of the building being printed neatly and clearly on or close to them; so that the dimensions of all and every part of the structure may be seen at a glance, without having to take the measurements from the scale which accompanies the drawings. If the drawings are dimensioned carefully, there will be no possibility of errors made in the drawings being carried on to the building itself. An undimensioned plan is practically valueless.

Plans in India are often drawn on *section paper*, that is, paper which is divided up into a number of squares of equal side, and these squares being again sub-divided usually into 100 small squares of equal size (the side of each large square is divided into ten equal parts). If paper is thus divided, a dimensioned and figured scale is unnecessary as the required measurements can be made directly from the small equal divisions into which the paper is divided by the squares. The length of each small division (side of small square) can be taken as any length rendered convenient by the size of the drawings that it is desired to make.

The scale to which each drawing is made should be attached to it. The same scale need not be used for all the drawings made, as the actual scale employed in any individual case depends upon the size and intricacy of design of the building. The following drawings of a building or other structure are generally prepared :—

(1) A GROUND PLAN or plan of the building. This is usually a horizontal sectional plan of the building taken at the level of the ground. The width of the foundations, and sometimes the projection of the space occupied by the roof, are also shown on the plan in dotted lines. It is also convenient to show in dotted lines the arrangement of the roof timbers on a portion of the plan, when the building is simple.

If the building has more than one story, a separate plan of each story, showing the distribution of the rooms, stair-cases, passages, etc., should be made.

(2) A VERTICAL SECTION OR SECTIONS.—If the building is a simple and symmetrical one, one or two vertical sections will be sufficient to show its exact shape; but where the shape of the building differs from place to place, a sufficient number of sections should be given to show the exact shape of all the different parts of the building. The position of the sections given should be carefully marked and properly lettered on the plan.

(3) FRONT AND SIDE ELEVATIONS, as well as elevations of dissimilar faces, should be given in order to show what the building will look like when completed.

In the case of a simple symmetrical building a half vertical section and half elevation may be combined together in one drawing; the section occupying one vertical half and the elevation the other half of the drawing. This can only be done when the right and left halves of the building are similar in every respect. In the same way a compound section may be given, the section being taken so as to show the detail of windows, doors, etc., and other features of the building,

and in this case the line on which the section is take should be clearly shown on the plan. What are called sections here are really sectional elevations, and not simple sections in the true sense of the word as understood in the projection of lines, planes and solids. The actual method of construction of plans does not fall within the scope of this work, but must be studied in detail separately, if the whole of the information contained in the plans of a building is to be thoroughly appreciated.

(4) WORKING DRAWINGS.—These are drawings of details which are too small to be shown on the scale to which the principal plans of the building have been constructed, but which must be supplied to the builder, in order to show him exactly how the different smaller parts of the building, such as the doors, windows, and the joints in the roof timbers, are to be constructed.

Such working drawings are useful in order to shorten the *specification* (see below), when the required detail cannot be briefly or accurately described in words. These drawings are made to a much larger scale than the rest of the plans. The details of doors, windows, and roof trusses may be shown from $\frac{1}{20}$th to $\frac{1}{40}$th of their full size, while the details of joints may be drawn to a scale of $\frac{1}{10}$.

In the Forest Department 3 copies of the plans are necessary. One is sent to the Conservator, one retained in the Divisional Office, and one sent to the officer who is to construct the building. This last should be dimensioned in the vernacular if that officer does not understand English well.

§ 215. THE SPECIFICATION is a detailed description of the nature and quality of the materials to be used in the construction of the building. The method in which the different parts of the building are to be constructed; the proportion and quality of the ingredients to be used in making mortar, concrete, plaster, etc.; as well as full particulars with regard to the supply of all the raw materials should be given in detail. If the

raw materials are to be supplied to the contractor, it should be clearly stated where the materials will be delivered.

§ 216. In cases where the contractor supplies the labour or materials, or both, and is paid by the quantity of work done, the rates at which he will be paid and the conditions of payment should be clearly specified.

The specification should be very carefully compiled, and the minutest detail thoroughly considered. It should be worded so as to allow of only one possible interpretation.

In the case of forest works in India, the specification at present usually serves as a guide to the executive officer who has to carry out the work, with regard to the nature of the materials to be used, and the method of construction to be followed. At present in India, so far as small forest works are concerned, it is rarely possible to find men who will contract for more than the supply of labour or, at the most, of some of the more common materials which can be locally obtained, and even then a mason cannot generally be found who is competent to build the walls, and also to put in the wood-work of the house. Consequently, the Forest officer in charge of the work generally has to arrange for the purchase of the materials, their carriage to the site of the building, as well as to generally supervise the work during its construction.

§ 217. In compiling the specification, it is usual to begin with those portions of the building which are under-ground and to work upwards. For example, in the case of houses the *specification* should show clearly, fully, and as briefly as possible, the details of the work, the manner in which it is to be executed, and the nature of the materials to be used. A detailed account of the way in which the construction is to be built, as well as of the kind of materials to be used, should be given in order under the following heads :—

1. Preparation of the foundation bed, including the disposition of the drains.

2. The brick-work or masonry in the foundations, plinth, and superstructure. The quality and nature of the stones or bricks as well as of the cementing material used, should be given; the description of the plaster, whether it is to be applied on both sides of the wall or on one only; the details of whitewashing, colouring, tarring, or painting, etc., together with the quality of the materials used and the method of applying them, should be given in full. Where bricks and stones are used in different parts of the same building, each must be considered separately.

3. *The roof.* Whether the roof truss is to be of iron or wood; the nature of the materials used; its construction, as well as the details of its component parts, and, if of wood, the methods to be employed for its protection against white-ants and moisture.

If wood is used the kind and quality of timber used, and the manner in which it is to be fixed in position should then be detailed. The use of properly seasoned wood should be insisted upon, while the proper construction of all joints in timber-work should be provided for.

4. *The floor.* Its nature, method of construction; whether it is to be solid, or provided with flues, as well as such other means as are to be adopted in order to prevent damp rising in it.

5. *Doors and windows.* The materials of which they are to be made, their construction, and the mode of hanging and glazing should be given.

6. All iron and brass-work connected with the foregoing items should be given together.

The quality and size of the hinges, the number to be fastened on to each door and window, as well as particulars regarding door handles, nails, screws, bolts, and other fastenings, should be carefully laid down.

7. Details concerning painting, varnishing, fittings, and

fixtures; staircases, ceilings, partitions, fire-grates, punkahs, etc., should then be given.

8. The cost of clearing away the rubbish and spare material, the construction of roads, clearing the ground, erecting enclosure walls and out-houses should be given last of all.

In short, the specification should embody a complete and full statement of the nature of all the materials to be used in the construction of the building, as well as the method in which each part of the building is to be constructed, and should be in sufficient detail to serve as a complete guide to the person who is responsible for its construction.

§ 218. In India, as it is at present not always possible to find contractors who will offer to construct petty works from specifications and plans (very few of the native forest contractors employed even understand what a plan is), it is usual to take out the quantities of the different materials required, and to explain to would-be builders the nature of the work to be done; and then to make an agreement with them as to the rates for which they will make the different parts of the building. It may be necessary even to supply the necessary materials, and to pay for the labour when the building is finished according to the volume of each kind of work done.

§ 219. QUANTITIES OF MATERIALS.—In taking out the quantities of materials required, it is convenient to follow some fixed rules, in order to prevent any items being forgotten; and to show the details of the measurements in a tabular form.

For example, begin with earth-work and take:—

(1) The preparation of the site for building;

(2) The excavation of the foundation beds.

Then take the foundation courses themselves (including the plinth), and estimate the quantity of masonry in each wall separately. If it is necessary to strengthen the foundation bed artificially, the volume of concrete required should also be computed.

The volume of masonry in the superstructure should be estimated, and the calculations for each wall shown separately, except in the case of two walls of exactly the same dimensions, allowances being made for the door and window openings and the necessary deductions made. External and internal walls should be shown separately. If more than one quality of masonry be used, the volume of each should be taken out by itself.

The volume of brick-work, if any, should be calculated separately.

The plastering of the internal and external walls, plinth, cornices, steps, pillars, verandah, ceiling, etc., should all be shown separately, and may advantageously be expressed in superficial feet, the thickness of the layer of plaster being given in the specification.

Whitewashing, distempering, or painting the walls should be also shown in superficial feet.

If the roof is terraced or arched, the quantity of masonry or brick-work necessary for its construction should be next taken out.

The volume of wood required in the building should then be calculated.

The scantlings should be arranged according to their size, the largest being placed first. The volume of each beam or plank should be taken out separately, and its position in the building stated; thus the planks for the floor should be shown separately from those required for the roof, walls, etc. The actual dimensions of the different scantlings, as well as the number of each required, should be detailed. The total volume of wood should be shown in cubic feet, or in superficial feet according as the sawing charges are paid for by the cubic foot or the superficial foot of surface sawn.

In estimating the volume of wood, allowance should be made for joints and waste.

The volumes of the different kinds of wood used should be shown separately.

The doors and windows may be estimated for at a fixed price, or if they are to be made, the quantity of wood required for each should be shown separately in detail. The frames for the doors and windows must not be forgotten.

Painting, if prescribed in the specification, should also be estimated for; the quantity of each colour required should be shown separately.

The weight of nails, screws, locks, hinges, door-handles, bolts, staples for supporting the roof gutter, as well as the roof guttering itself, should be shown separately.

The cost of clearing away the rubbish from the site after the building is completed; any works which may be necessary to ensure the stability of the building should be carefully estimated and shown in detail by themselves.

§ 220. In calculating the actual quantities of materials required, in simple buildings the different parts of the building should be briefly but distinctly described in words; for example, the external long walls, the main long walls, internal cross walls, etc. Walls of the same height and thickness should be entered one after the other, so as to facilitate the calculation of their cubic contents; the measurements should be taken to the nearest greater ¼ of a foot.

The total volume of each kind of material or work, such as excavation of earth, masonry in the foundations or superstructure, brick-work, beams or planks for which different rates are paid, should be taken out and shown separately.

The tabular form given below is that adopted by the Public Works Department, and is perfectly suitable for all the requirements of Forest officers. It has been partially filled in, so as to make its use quite clear.

Table of Quantities.

Kind of work.	Particulars.	Number.	Dimensions. Length in ft.	Breadth in ft.	Height in ft.	Area or Contents.	Total.
Earthwork	(a) Levelling site, including clearing all vegetable growth.	1	100	100	2	20,000	
	(b) Excavation of foundation beds.						
	For outer long walls.	2	35	2½	1½	263	
	For outer short walls.	2	27	2½	1½	203	
	For inner long walls.	2	35	2½	1½	263	
	For partition walls.	2	12	2½	1½	90	
	For short walls for kitchen.	2	5	2	1½	37	
							20,856 cub. ft.
Masonry (a) in foundations and plinth.	Outer long walls.	2	35	1½	3	315	
	Outer short walls.	2	27	1½	3	243	
	Inner long walls.	2	35	1½	3	315	
	Partition walls	2	12	1½	3	108	
	Short walls for kitchen.	2	5	1½	3	45	
							1,026 cubic ft.
			Etc.	Etc.			

§ 221. THE ESTIMATE is formed with the help of the plan and specification; the quantities of the materials used are calculated from measurements taken from the plan; while the quality of the materials, as well as the rates to be paid for labour in constructing the several parts of the building, are taken from the specification. The materials should be estimated for at the local rates in force for the time being. The estimate should give the total cost of the building shown in the plans, built according to the conditions laid down in the specification.

If some of the materials have to be obtained from a distance, the cost of carriage must not be forgotten.

The cost of the materials used in the building, and the cost of construction of the different parts, should be kept separate, unless the rates given for the work in question include the cost of the material and its carriage to the site of the work.

Five per cent. of the total cost of the structure is added to cover the extra cost of such small items as may subsequently be found necessary or may have been forgotten when framing the estimate, as well as to cover slight changes in the rates paid for materials and labour which may have occurred during the interval.

In the construction of Government works the estimate should be a fairly liberal one, as when once sanctioned it cannot be exceeded unless for very special reasons. A form used by the Public Works Department for the abstract of cost is given below:—

Abstract of Cost.

Quantity.	Items.	Rate.	Cost.	Total.
			Rs. A. P.	Rs. A. P.
2,000 cubic feet	Levelling site of Building .	5 Rs. per 1,000	10 0 0	
856 cubic feet	Excavation of foundation bed	Rs. 5 per 1,000	4 4 6	14 4 6
1,026 cubic feet	Masonry in foundation and plinth . . .	Rs. 12 per 100	123 2 0	123 2 0
Etc.	Etc.	Etc.	Etc.	Etc.
	Total Rs.			
	Contingencies at 5 per cent.			
	Grand Total R			

APPENDIX I.

BULL'S PATENT TRENCH KILN.

By C. E. Dupuis, F.C.H.

(Executive Engineer, Irrigation Branch, North-West Provinces, India).

Bricks for large Government works in Northern India are almost always burnt close to the site in a Bull's Patent Trench Kiln.

The advantages of this form of kiln are numerous, but none is greater in practice than its simplicity. The construction of a kiln involves nothing but a little exceedingly simple earthwork, and a kiln can be constructed, bricks moulded, and burning started in any convenient field in a very few days.

The kiln is a modification of Hoffman's Perpetual Kiln; but whereas Hoffman's kiln is an elaborate and expensive brickwork erection, Bull's is merely a trench in the ground.

The principle is, however, the same, and consists essentially of an annular chamber in which the burning is carried on continuously, the fires travelling round and round the chamber; the burnt bricks being removed from behind, and the unburnt bricks filled in in front of the fires as they advance (see plate, Fig. 1).

The draught of the fires is also carefully arranged by movable stops, dampers and chimneys; so that the air for the fires is always supplied through recently-burnt bricks, and consequently reaches the fires exceedingly heated; and at the same time the cooling of the bricks at the point of removal is accelerated; and the heated products of combustion pass for some distance through layers of unburnt bricks, ready for burning, and so assist in drying them thoroughly, and in heating them to a very considerable degree, before the fires actually reach them.

The kiln may be circular in plan, but it is more economical of space to make it in the shape of a flattened ring (see plate, Figs. 1 and 2), the greater part of the circumference consisting of two long straight reaches separated only by a wall; these are connected by sharp semi-circular curves at either end; a further advantage of this shape is that firing is distinctly easier on the straight than round the curve, and the average outturn is better.

This kiln may be made of any convenient size depending on the number of bricks to be burnt, and on the rate at which they have to be turned out. A kiln about 100 yards long (that is about 220 yards in circumference), with a trench 20 feet wide by 8 feet deep, will turn out about

10,000 burnt bricks per diem from one set of fires; a kiln of this size can, if necessary, be worked with two sets of fires; as the fires with the bricks that are in process of heating and cooling, from the point at which the kiln is being loaded to the point at which the bricks are being removed, will not occupy one-half of the circumference of the kiln (see plate, Fig. 1).

The rate at which the fires advance depends of course on many things, especially the quality of the wood burned, and the dryness or dampness of the weather, but in an average case the fires will advance about from 6 to 10 feet a day.

The working of a kiln will best be understood by taking an average case and describing the processes required in detail.

First a site must be selected where suitable earth is obtainable, as near as possible to the work, and a piece of land appropriated for the brickfield.

It is worth noting in this connection that a brickfield wants a good deal of space. The kiln itself, earth-pits, moulding benches, drying floors, drying stacks, stacks of burnt bricks, stacks of wood, shelter sheds and pathways occupy a large area, and it hampers the work exceedingly if materials must constantly be shifted to make room.

The kiln is then marked out on the ground and excavated. If the soil is firm, the vertical sides of the trench in the natural ground require only a little trimming and plastering; but sometimes where the soil is not firm, the sides of the trench has to be faced with a rough mud walling.

The depth of the kiln is generally so adjusted (see Fig. 3) that about two-thirds is in excavation, *i.e.*, below the natural surface of the ground and one-third above.

The kiln being ready, a commencement is made with the loading at any convenient point. The kiln is loaded up to its full height from that point onwards in one direction.

The bricks are carefully loaded in a particular manner, the result of which is that the whole body of the kiln is filled with unburnt bricks (loosely stacked with air spaces in all directions) containing rectangular vertical shafts about 18 inches square at the bottom and 9 inches square at the top, at intervals of about 3 feet apart across the kiln, and 4 feet apart longitudinally. These vertical shafts form the fire-holes.

The top layer consists of bricks laid flat and placed close together; the tops of the shafts (fire-holes) are also closed in with bricks, and the whole upper surface is then covered over with from 3 to 6 inches of sandy earth and ashes rendering it approximately airtight.

At intervals of about 25 feet complete vertical joints, about 3 inches wide are left in the stacking, for the full height and width of the kiln; these are for the insertion of the *stop dampers* (see Fig. 8). As soon as a length of about 100 feet of the kiln has been loaded, the dampers are placed in the joint (see plate, Figs. 1 and 6) at, say, 100 feet from the point where the loading of the bricks commenced, and the joint is then made as airtight as possible by caulking with wet clay. The chimneys are erected over a row of fire-holes (see Figs. 6 and 7) near the damper (the tops of the fire-holes

being of course opened out), and the fires are started at the point where the loading commenced. Special care is required in the regulation of the draught at first, and the points of the brick face where the loading started have to be caulked. The outturn at first is necessarily poor, and will continue so until the operation of burning is well under way.

The fires are started in the first few sets of fire-holes (generally 4 or 5 rows) and kept going for 2 or 3 days, the wood being fed into the fires by dropping it in through the tops of the fire-holes.

As soon as the bricks around the holes appear thoroughly burnt, the fires are advanced to the next set of holes. After 2 or 3 days, in favourable weather, it will be generally possible to advance the fires every day.

While the fires are actually burning, the fire-holes in use are closed by saucer-shaped iron dampers (see Fig. 9) that with the aid of a little sand round their edges are sufficiently airtight. As soon as the burning in any set of holes is complete, the iron dampers are moved forward with the fires and the holes closed in with bricks and covered with sand as before.

As soon as the fires have moved forward about 25 feet, the stop dampers must be shifted forward to the next vertical joint and the chimneys moved on correspondingly, the openings left by their removal being carefully closed as before.

As the fires advance further from the original starting-place, the caulking of the joints must then be removed to admit more air to the fires and to cool the burnt bricks.

By the time that the fires have advanced about 100 feet, the bricks at the starting-point will be cool enough to be removed. From the time that the work of removing the bricks commences, the kiln may be considered to be in full work.

The work of loading the kiln goes on continuously a little ahead of the main damper and chimneys, which are moved forward 25 feet every third or fourth day. The fires are continuously advancing about two holes (that is, 6 to 8 feet) a day, and are about 75 feet behind the chimneys. About 100 feet behind the fires the burnt bricks are being removed.

It is thus seen that the various processes in connection with one set of fires occupy a length of at least 200 feet, and this is the least circumference that will suffice in an ordinary kiln. As a matter of fact, they are seldom made less than about 300 feet in circumference, and often much more, as for instance when 2 sets of fires are to be employed.

If a very small number of bricks are to be burnt, the principle of Bull's Patent Trench Kiln can often be applied advantageously to a short straight trench, but in such a case the outturn is not likely to be very good.

An average example of Bull's kiln may be taken as a trench 12 feet wide by 6 feet deep and 300 feet in circumference, burning one set of fires and turning out about 5,000 bricks per diem, of which 70 per cent. should be first class, 20 per cent. second class and overburnt, 5 per cent. third class, and 5 per cent. unburnt and broken.

The consumption of wood [common kinds, such as Dhak (*Butea frondosa*), etc.] should not exceed 6,000 cubic feet stacked per lakh (100,000) of bricks loaded, the wood being measured in stacks ready for use.

The fire-holes being only 9 inches square at the top, the largest pieces of wood must not be more than about 8 inches in diameter. Generally speaking, pieces of wood about 6 inches in diameter and 2 to 3 feet long are most suitable. All the pieces must be fairly straight. The degree of burning necessary is a very delicate matter, and which can be only learnt by experience: it is quite impossible to give rules on the subject. It is absolutely essential that the head fireman should be capable and experienced: but speaking very broadly, the bricks have to be kept at an intense white heat for about 24 hours, and at lower degrees of heat for several days; and it is essential that neither the heating nor the cooling should be too rapid. The firemen judge themselves of the progress of the burning by looking into the fire-holes, and feed in the wood as appears to them necessary.

Too great heat will result in the partial melting of the bricks (especially those containing much sand and iron), and this is often followed by the subsidence of a considerable area of the kiln, which, besides actually damaging a very large number of bricks, blocks the fire-holes and air passages, and interferes seriously with the firing for a very much larger number. Too little heat will result in the outturn of an excessive proportion of 2nd and 3rd class bricks

The kiln surface naturally subsides in the process of burning to the extent of about 8 per cent. of the full height. The amount of the subsidence of the kiln is also a guide to the firemen in burning.

In burning a large number of bricks by this method it is essential to economical working that the gangs of men employed on the various processes be carefully proportioned. If, for instance, too many moulders be employed, there will be an accumulation of sun-dried bricks, cumbering the ground and liable to be damaged by a chance shower of rain; if too few, the fires will have to be checked and damped down while waiting for bricks, and this is of course ruination to the outturn.

Before starting work, the number of bricks to be turned out per diem should be determined, the size of the kiln designed, and the number of men in each gang assigned proportionately. The numbers can, of course, be varied as found necessary, but the progress of the fires, with a view to the best possible outturn, should be allowed to determine all other factors, any attempt to hurry or check the fires being usually disastrous.

The bricks should be allowed to cool slowly, and if they can be left in the kiln until absolutely cold, so much the better. Sometimes when bricks are wanted quickly, they have to be removed when they are only just cool enough to handle: this, of course, admits the draught upon the bricks while still very warm, and generally causes a great many of them to crack.

It may, therefore, be considered desirable to make the kiln fairly large, so that a considerable length of cooling bricks may be left behind the fires without interfering with the progress of the work.

Tiles and pipes can be burned in these kilns as well as bricks. It is usual to burn them together with bricks, stacking them amongst the bricks, away from actual contact with the fire-holes to save breaking in firing, and because the tiles are more valuable, more easily broken, and more easily injured by overburning than bricks.

The following figures and sketches (see plate), taken from an actual instance of a Bull's kiln, may be considered typical. About 15 lakhs of bricks were required for the construction of an important torrent work on the Eastern Jumna Canal, in the Saharanpur district, North-Western Provinces, during the winter of 1894-95. The winter being cold and wet, the work was much delayed, and it became necessary to turn out the bricks in a very short time. A large two-fire kiln was therefore constructed of the dimensions shown in Figs. 2 and 3.

The fire-holes were 3 feet apart from centre to centre transversely and 4 feet apart from centre to centre longitudinally. There were six fire-holes in a line across the trench, and six such lines of holes in each block 23 feet long between successive damper joints (see Fig. 4).

Each such block, containing in this case 36 fire-holes, is known technically as a "*chimney*," from the fact of the chimney being set up afresh over each block as the fire advances.

In the kiln now being described each "chimney" covered a kiln space of 23 feet by 17 feet 6 inches, contained 17,000 bricks, and took two days to burn, the fires advancing 3 lines of holes, and the outturn being 8,000 bricks daily. The consumption of wood was about 1,200 cubic feet stacked per chimney, or 7,000 cubic feet stacked per lakh. The kinds of wood chiefly used were Dhâk (*Butea frondosa*), Kikar (*Acacia Arabica*) and Shisham (*Dalbergia Sissoo*). The fires were maintained in three lines of holes (see Fig. 6). There were 15 courses of bricks on edge in the loaded kiln.

The funnels which were placed over the line of fire-holes next but one to the damper, to take off the products of combustion and heated air, after it had passed through the required length of bricks, are shown in Figs. 1, 6 and 7. They are fitted with handles for convenience in moving, and are stayed with ropes when set up to prevent their being blown over.

The *damper* (Fig. 8) consists of several sheets of thin iron about 2 feet wide, and as long as the kiln is deep. These fit into H—section wrought iron slide bars, which keep the whole fairly airtight. They are fairly easily fixed in place in one of the vertical joints, and are then puddled up round the top with wet clay to make them airtight.

DESCRIPTION OF FIGURES IN THE PLATE ILLUSTRATING BULL'S PATENT TRENCH KILN.

Fig. 1 is a sketch of a large trench kiln burning with two sets of fires. The relative positions of the damper, chimneys, bricks that are being

heated, fires, bricks that are cooling, bricks that are being removed, space from which the burnt bricks have been removed, and the unburnt bricks that are being loaded, for both sets of fires are shown. Scale 20 yards to the inch.

Fig. 2 is a plan of the empty kiln ready for the loading with unburnt bricks. Scale 20 yards to an inch.

Fig. 3 is a cross section along the line A B. Fig. 2, showing the dimensions and construction of the empty trench kiln. Scale 20 feet to an inch.

Fig. 4 is the plan of "one chimney," as the mass of bricks between two consecutive damper joints is technically called. The position and size of the fire-holes and damper joints are shown in this drawing. Scale 10 feet to one inch.

Fig. 5 is a longitudinal section along the line C D, Fig. 4, to show the size and relative position of the fire-holes in which the wood to be burnt is placed. The tops of the fire-holes when not actually in use are covered over with bricks. The whole of the top of the kiln is covered over with a layer of sand and ashes about 6 inches thick, so as to prevent the heat from escaping, without passing through the bricks which are to be burnt, and out of the chimneys provided for that purpose. Scale 10 feet to the inch.

Fig. 6 is a longitudinal section through part of a loaded kiln, to show how the process of brick-burning is carried on and how the heat from the fires is utilized in drying and heating the unburnt bricks, instead of being allowed to escape without being used, as is the case in many of the brick kilns and clamps in common use.

The arrows show the direction in which the heated air is led, and indicate how fully it is utilized before it is allowed to escape. Scale 20 feet to an inch.

Fig. 7 shows in detail the shape and construction of one of the three chimneys shown in plan in Fig. 1 and in longitudinal section in Fig. 6. The three chimneys employed are placed in one of the same transverse row of fire-holes. Two flues open into each chimney, as shown in the sketch. The figure is a vertical section along the line E F, Fig. 4. The other four fire-holes in the line open similarly into two other chimneys, and thus the draught through the kiln is made as uniform as possible. Sections of the chimney along the lines G H and I J are given. Scale 10 feet to an inch.

Fig. 8 shows in elevation one of the iron sheets of which the damper is composed. The method of fixing the successive sheets into H—section wrought iron slide bars is shown in plan. Scale 10 feet to the inch.

Fig. 9 is a vertical section through the top of one of the fire-holes in which the fire is still burning, showing one of the iron fire dampers which cover the fire-holes when the fires are burning in them.

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